CARBON AND NITROGEN DYNAMICS UNDER AGRI–HORTICULTURE SYSTEM

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Dedicated to my
beloved parents
and guide

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
UNIVERSITY OF AGRICULTURAL SCIENCES
BANGALORE-560065

CERTIFICATE

This is to certify that the thesis entitled **"CARBON AND NITROGEN DYNAMICS UNDER AGRI–HORTICULTURE SYSTEM"** submitted by **Mr. ADIVEPPA MALLAPPA ASANGI, ID No. PALB 5098** in partial fulfillment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** in **SOIL SCIENCE AND AGRICULTURAL CHEMISTRY** to the University of Agricultural Sciences, Bangalore, is a record of *bona-fide* research work carried out by him during the period of his study in this university under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or any other similar titles.

BANGALORE
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CARBON AND NITROGEN DYNAMICS UNDER AGRI–HORTICULTURE SYSTEM

ADIVEPPA MALLAPPA ASANGI

ABSTRACT

Field experiments were conducted to study carbon and nitrogen dynamics under agri–horticulture system during *kharif* 2017 and 2018 in an established custard apple orchard at All India Coordinated Research Project on Dryland Agriculture, UAS, GKVK, Bangalore. Soil of the experimental site was sandy clay loam in texture, slightly acidic in nature with medium fertility. The experiment was laid out in randomized complete block design with three replications. There were fifteen treatment combinations consisting of eight sole crops *viz.,* finger millet, fodder maize, field bean, niger, chilli, cowpea, foxtail millet and custard apple and seven intercrops with custard apple.

The pooled analysis revealed that the carbon and nitrogen fractions at different depths of soil varied significantly among different treatments due to custard apple based agri–horti system. At 0–15, 15–30, 30–60 and 60–90 cm depth of soil, treatment CA + Cowpea recorded significantly higher carbon fractions viz., soil organic carbon (6.57, 6.12, 4.16 and 3.13 g kg^{-1}, respectively), microbial carbon (294.50, 179.73, 93.51 and 59.93 mg kg^{-1}, respectively), water soluble carbon (52.71, 39.44, 24.94 and 17.82 mg kg^{-1}, respectively), active/labile carbon (656.05, 560.40, 464.45 and 350.99 mg kg^{-1}, respectively) and total carbon (7.19, 7.08, 5.40 and 4.50 g kg^{-1}, respectively), and nitrogen fractions viz., available nitrogen (105.90, 93.62, 71.93 and 51.34 mg kg^{-1}, respectively), ammonical nitrogen (41.79, 42.79, 32.68 and 24.99 mg kg^{-1}, respectively), nitrate nitrogen (42.70, 34.01, 24.31 and 14.41 mg kg^{-1}, respectively) and total nitrogen (637.56, 581.17, 518.26 and 391.49 mg kg^{-1}, respectively). Soil inorganic carbon was found significantly higher (0.94 and 1.36 g kg^{-1}) under fodder maize alone treatment at 0–15 and 15–30 cm depth of soil, respectively, however it was non-significant at 30–60 and 60–90 cm depth. Irrespective of treatment, both carbon and nitrogen fractions were found to be decreased with increase in depth of soil except soil inorganic carbon. Soil analysis before sowing and after harvesting of crops during both years showed that there was variation in soil fertility among the treatments due to significant changes in soil physical, chemical and biological properties due to custard apple based agri–horti system.

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(**R. KRISHNA MURTHY**)
Major advisor

ಕೃಷಿ–ತೋಟಗಾರಿಕೆ ಪದ್ಧತಿಯಲ್ಲಿ ಇಂಗಾಲ ಮತ್ತು ಸಾರಜನಕದ ಬದಲಾವಣೆ

ಅಡಿವೆಪ್ಪ ಮಲ್ಲಪ್ಪ ಆಸಂಗಿ

ಪ್ರಬಂಧದ ಸಾರಾಂಶ

ಕೃಷಿ–ತೋಟಗಾರಿಕೆ ಪದ್ಧತಿಯಲ್ಲಿ ಮಣ್ಣಿನಲ್ಲಿರುವ ಇಂಗಾಲ ಮತ್ತು ಸಾರಜನಕದ ಬದಲಾವಣೆ ವಿಷಯದ ಅಧ್ಯಯನವನ್ನು ಮಳೆಯಾಧಾರಿತ ಕೆಂಪು ಮಣ್ಣಿನಲ್ಲಿ 2017 ಮತ್ತು 2018ನೇ ಸಾಲಿನ ಮುಂಗಾರಿನಲ್ಲಿ ಗಾಂಧಿ ಕೃಷಿ ವಿಜ್ಞಾನ ಕೇಂದ್ರದ, ಖುಷ್ಕಿ ಬೇಸಾಯ ಸಂಶೋಧನಾ ಕೇಂದ್ರದಲ್ಲಿ ಯಾದ್ರಿಚ್ಛಿಕ ಸಂಪೂರ್ಣ ವಿಭಾಗ ವಿನ್ಯಾಸದಲ್ಲಿ ಹದಿನೈದು ಉಪಚಾರಗಳುಳ್ಳ ಪ್ರಯೋಗವನ್ನು ಮೂರು ಬಾರಿ ಪ್ರತಿರೂಪಿಸಿ ಕೈಗೊಳ್ಳಲಾಯಿತು. ಈ ಉಪಚಾರಗಳು ಎಂಟು ಪೂರ್ಣ ಬೆಳೆಗಳಾದ ರಾಗಿ, ಮೇವಿನ ಮೆಕ್ಕೆಜೋಳ, ಅವರೆ, ಗುರೆಳ್ಳು, ಮೆಣಸಿನಕಾಯಿ, ಅಲಸಂಧೆ, ನವಣೆ ಮತ್ತು ಸೀತಾಫಲವನ್ನು ಏಳು ಬೆಳೆಗಳೊಂದಿಗೆ ಅಂತರ ಬೆಳೆಗಳಾಗಿ ಪರಿಕ್ಷಿಸಲಾಯಿತು.

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LIST OF ABBREVIATIONS

ACID.P	Acid phosphatase
AG. S	Aggregate stability
ALK.P	Alkaline phosphatase
ATER	Area time equivalent ratio
AV.K_2O	Available potassium
AV.N	Available nitrogen
AV.P_2O_5	Available phosphorus
BD	Bulk density
C.D.	Critical difference
CA	Custard apple
CEC	Cation exchange capacity
CEY	Custard apple equivalent yield
DAP	Diammonium phosphate
DAS	Days after sowing
DAT	Days after transplanting
DHA	Dehydrogenase activity
EC	Electrical conductivity
FYM	Farmyard manure
IR	Infiltration rate
LC	Labile carbon
LER	Land equivalent ratio
MBC	Microbial biomass carbon
MBN	Microbial biomass nitrogen
MBP	Microbial biomass phosphorus

MOP	Muriate of potash
MWD	Mean weight diameter
MWHC	Maximum water holding capacity
NH_4–N	Ammonical nitrogen
NO_3–N	Nitrate nitrogen
NS	Non significant
RWUE	Rainwater use efficiency
RCBD	Randomized complete block design
S.Em±	Standard error of means
SIC	Soil inorganic carbon
SOC	Soil organic carbon
SOM	Soil organic matter
SYI	Sustainable yield index
TC	Total carbon
TN	Total nitrogen
TPF	Triphenyl formazon
TTC	Triphenyl tetrazolium chloride
UA	Urease activity
WSC	Water soluble carbon

LIST OF UNITS AND SYMBOLS

Mg m^{-3}	Megagram per cubic meter
%	Per cent
cm hr^{-1}	Centimetre per hour
dS m^{-1}	Deci Siemens per meter
g kg^{-1}	Grams per kilogram
mg kg^{-1}	Milligrams per kilogram
@	At the rate of
r	Correlation coefficient
µg	Microgram
ºC	Degree celsius
hr day^{-1}	Hours per day
viz.,	Namely
km hr^{-1}	Kilometre per hour
mm day^{-1}	Millimetre per day
cm	Centimeter
kg ha^{-1}	Kilogram per hectare
kg ha–mm^{-1}	Kilogram per hectare millimetre
t ha^{-1}	Tonne per hectare
Mg ha^{-1}	Megagram per hectare
g cc^{-1}	Gram per cubic centimetre
nm	Nanometre
et al.	And others
cmol (p^{+}) kg^{-1}	Centimoles per kilogram

I INTRODUCTION

Soil is a heterogeneous material occurring as a thin layer on the surface of the earth's crust. Soil is very much important in the context of crop production, since it provides anchorage and nutrients to plants. Today's agriculture practices are aiming at higher productivity per unit area rather than sustainable production which is causing deterioration of soil fertility and productivity. It is known that it takes thousands of years for developing one inch of soil layer. The current practices of cultivating crops in drylands are more difficult because of higher dependence on external inputs and poor fertility status. In this context maintaining soil fertility for sustainable crop production is more important.

Soil organic matter is main source of nutrients that supplies mainly carbon, nitrogen, phosphorus and sulphur to the crops. Therefore, decline in soil carbon generally reduces crop productivity. Degradation of crop residues and organic wastes play a major role in global carbon and nitrogen cycle. In rainfed arid, semiarid and sub humid regions of India, next to soil erosion with poor rain water management, depletion of nutrients due to lower soil organic carbon stock is responsible for soil degradation results in poor soil quality, loss of favourable biology and occurrence of multiple nutrient deficiencies leading to lower productivity (Srinivasarao *et al.,* 2013). Intensive cropping over the years encourages oxidative losses of C due to continuous soil disturbance, while cropping results in accumulation of C in soil through addition of crop residues which either results in net addition or depletion of soil C stocks (Majumder *et al.,* 2008). The soil organic carbon enhances the soil quality by improving soil structure and aggregation, water retention and use efficiency, nutrient retention and regulates gaseous emissions (e.g., CO_2, CH_4, N_2O) which moderate atmospheric chemistry and regulate climate change (Rattan Lal, 2016). Soil carbon exists in organic and inorganic forms. Nitrogen constitutes about 40% to 50% of the total dry matter. Maintaining a better C:N ratio in soil is essential to supply nitrogen to crops in proper quantity.

Arid regions which cover 12 per cent of the India's total geographical area facing several biophysical constraints because of the poor production systems adopted in these

areas. At the global level, it appears that our country slowly moving towards food crisis because of the reduced productivity of crops, soil fertility and decreasing land area under agriculture. Monoculture is often a common practice that results in crop failure due to frequent droughts associated with climate change. Under such situations, adopting appropriate cropping systems which integrate suitable crops with fruit trees has been found sustainable. Cultivation of most suitable fruits and seasonal intercrops in the cropping systems under dryland condition is very essential. For sustainable management of drylands in order to enhance the economic viability of the cropping system, partial shift from the existing input intensive cropping system to low input requiring system is essential. Inclusion of cereals and pulses including oil seeds in horticulture based production systems would increase the overall sustainability and efficiency of the system which would be of much helpful to the resource poor farmers under dryland conditions.

In order to get higher yields, maintain soil health, conserve environment and to meet daily livelihood requirement of human and animal population, diversification of cropping system is essential (Padhi and Panigrahi, 2006). Intercropping is one crop diversification approach that aims to increase productivity per unit area through judicious use of land resources and inputs. The intercropping systems not only provide various requirements of a farmer, but also harness the land resources efficiently. Development of any intercropping system which is economically feasible and environmentally viable depends largely on selection of compatible crops, planting time, planting geometry and management of nutrients under rainfed conditions. Many studies have reported that the total yield can be increased with intercropping over sole cropping. This is possible, because in an intercropping system, the component crops use resources efficiently, so that the crops grown together complement each other and results in effective use of resources as compared to crops grown alone (Willey, 1979). To avoid the mutual competition under intercropping system, proper care is required in selecting component crops by considering fast growing early maturing crops along with slow growing late maturing ones.

The agri–horticulture system is becoming a common practice in order to grow fruits and field crops on the same piece of land in order to attain higher income. To

increase the significant area under agri–horticulture systems horticultural development programmes were introduced in watersheds considering the importance of fruits in human diet. The indigenous fruits available locally play a vital role in the nutrition and health of rural population of India, since these fruits are major source of vitamins and minerals. Since, India is blessed with different climatic conditions ranging from tropical to temperate; it is possible to cultivate different varieties of fruits and crops. So, this has led to the adoption of different agri–horticulture systems suitable to different climatic conditions.

Custard apple (*Annona squamosa* L.), is an edible fruit native to Tropical America, which distributed widely across tropical and subtropical regions. It is rich in potassium, magnesium, vitamin A, calcium, copper, phosphorous and fibre content. It is commonly grown on marginal lands and rocky hilly areas with minimum inputs (Rajput, 1985). Custard apple has several synonyms such as *sithaphal,* sugar apple, *sharifa*, sweet sop *etc.*, and genus *Annona* contains more than 70 species of which only five of them namely, Custard apple (*Annona squamosa* L.), Pond apple or Ram phal (*Annona reticulata* L.), Cherimoya or Lakshman phal (*Annona cherimola* L.), Sour sop (*Annona muricata* L.) and Hanuman phal (*Annona atemoya* L.) produce edible fruits. India is one of the major producers of custard apple in the world. In India, an estimated area under custard apple is 36,830 ha with the production 2,89,010 tonnes and the productivity of 6.76 tonnes ha^{-1}. In Karnataka the area under custard apple is about 1,740 ha with production of 14,450 tonnes and productivity of 7.4 tonnes ha^{-1} (Anon., 2016).

Custard apple is a small drought resistant small tree, grows to a height of 5 to 9 feet. Normally fruit bearing starts at the age of 4 to 6 years and bearing continues up to 12 to 15 years and later declines. Depending on the climatic condition of the region, harvesting of fruits may extend from August to November. Since custard apple fruit is climacteric in nature, it is harvested in unripe condition after maturity when the skin between the segments turns creamy yellow. Arka Sahana is a hybrid, developed at Indian Institute of Horticultural Research (IIHR), Hessaraghatta. Harvesting of Arka Sahana fruits may extend from September to October/November and mature fruits take about 6

to7 days to ripe. On an average, 12 tonnes of fruits can be harvested per hectare and the crop is drought resistant (Anon., 2014).

There are some research work being carried to assess the performance of field crops when incorporated with horticulture crops and their effect on soil health under dryland situations. Therefore, development of a suitable intercropping technology under custard apple was felt essential to enhance the productivity as well as monetary advantage to farmers. Further sustaining soil quality under declining soil fertility with intensive monocropping is essential. Monitoring sustainable soil quality involves assessing carbon and nitrogen dynamics in a cropping system. The present study on **"Carbon and nitrogen dynamics under agri–horticulture system"** was carried out during *kharif* seasons of 2017 and 2018 at All India Coordinated Research Project for Dryland Agriculture (AICRPDA), UAS, GKVK, Bangalore, in an ongoing experiment entitled "Evaluation of custard apple based agri-horti system involving cereals and pulses" which was started during *kharif* 2012 in a custard apple orchard (planted in 2009) and various intercrops were sown during *kharif* and left fallow during *Rabi* and summer and the experiment is being continued with same set of treatments with the following objectives.

1) To study the carbon and nitrogen dynamics under agri–horticulture systems.
2) To assess the soil physical, chemical and biological properties under agri–horticulture systems.
3) To assess the productivity of land under diversified cropping systems.

II REVIEW OF LITERATURE

Cropping systems are the main components which determine the soil fertility in any agriculture practice. Different cropping systems have different capacity to add carbon to soil. Sustainable crop production is uncertain in rainfed regions mainly due to recurring droughts and other inherent factors. Alternate land use systems for arid regions as good ameliorative measures have already been established. The biggest challenge in tropics is the need of developing suitable rainfed agri–horti models that will ensure sustained crop production without causing degradation to the non-renewable resource base. Growing annual crops with perennial plants (Agri–horticulture, agroforestry *etc*.) is an essential approach as per as the sustainable crop production and soil fertility is concerned in dryland conditions. The effect of different agri–horticulture systems on soil fertility is not well understood. Custard apple as a tropical plant that can be efficiently grown intercropping with short duration crops under these conditions. Hence, the effect of different intercropping as well as sole cropping practices on changes in soil physical, chemical and biological properties, carbon and nitrogen dynamics and yield of field crops associated with custard apple in an agri–horticulture system have been reviewed and presented in this chapter under the following headings:

2.1 Concept and impact of agri–horticulture/agroforestry systems on different crops

2.2 Effect of agri–horticulture systems on physical, chemical and biological properties of soil

2.3 Effect of agri–horticulture systems on carbon dynamics in soil

2.4 Effect of agri–horticulture systems on nitrogen dynamics in soil

2.1 Concept and impact of agri–horticulture/agroforestry systems on different crops

The term ‘agro-forestry’ describes integrated practice of growing arable crops in association with the tree species. Yield advantage in intercropping occurs when component crops differ in their use of growth resources in such a way that when they are grown in combination, they are able to complement each other to make overall better use of resources than when grown separately. In terms of competition this means that in some

way the component crops are not competing for exactly the same resources thus, intercrop competition is less than intra crop competition, maximizing the degree of complementarities between the components and minimizing intercrop competition. On this basis, intercropping advantages are more likely to occur when the component crops are different (Willey and Roberts, 1976). Site conservation and optimal productivity are cardinal aspects of all agroforestry land management system around the world (Nair, 1993). The various agroforestry systems around the world are classified based on structural, functional, socio-economic and ecological attributes, to evaluate the existing agro-forestry system and to develop action plans for their improvement. Based on structural component, agro-forestry is divided into agri-silviculture (crops, pasture/animals and trees), silvi pastoral (pasture/animals and trees) and agro-silvipastoral (crops, pasture/animals and trees).

Area time equivalent ratio (ATER) is only appropriate in systems with component crops of contrasting maturities such as 110 days in maize and 170 days in pigeon pea. If component crops have similar growth durations, ATER values will be similar to LER. When the difference between growth durations of component crops is substantial, time becomes an important element and ATER is considered to be more appropriate index of efficiency of the system (Ofori and Stern, 1987). Intercropping of food legumes *viz.,* black gram, green gram and cowpea in Java citronella increased the land use efficiencies to the tune of 40-46 per cent as measured by area time equivalency rate (ATER) index (Prakasa Rao *et al.,* 1988). Sarkar and Shit (1990) observed higher ATER value (1.00) with maize + pigeonpea intercropping system followed by maize + soybean (0.85 ATER). When trees and crops grow together on same piece of land (simultaneous), trees may have positive (complementary) and negative (competition) effects on crops. These interactions are both below and above ground. Tree-food crop interaction can be classified broadly in three zones as: a zone of light and root competition (under tree crown), a zone of root competition (a distance beyond tree crown), and a zone of open cropped areas with minimal tree interference (Rao *et al.* 1998). Bheemaiah and Subrahmanyam (2001) reported that the yield of blackgram and cluster bean were significantly higher in their pure stands than in agri–

horticultural intercropping system. Owere *et al.* (2001) recorded higher land equivalent ratio (LER) up to 1.30 and 1.29 in finger millet/pigeonpea and sorghum/pigeon pea intercropping at 2:2 row ratio.

Mishra and Swain (2002) reported that the effects of intercrops on growth of the fruit crops. During the first year, groundnut resulted in the highest growth rate in respect of plant height and girth in mango, cashew and ber. Mango in combination with groundnut intercrop had the highest net return (Rs. 6000 ha^{-1}). The results indicate that pulse crops, *i.e.* arhar and black gram, could be profitably grown as intercrops in fruit orchards during the pre-bearing stage in this region.

Basavarajappa *et al.* (2003) revealed that significantly higher foxtail millet grain yield (1609 kg ha^{-1}) was recorded in sole crop than intercrop treatments. The extent of reduction in grain yield ranged from 39 to 44 per cent when compared to economic yield of sole foxtail millet. The grain/seed yield of cotton, pigeon pea, sesamum, castor and mesta in sole cropping were significantly higher than that recorded in intercropping system. The extent of reduction in grain/seed cotton yield of intercrops was 52 per cent as compared to sole crop yield. In extent of reduction in yield of castor and mesta under intercropping were 43 and 42 per cent, respectively.

Srilakshmi (2003) conducted an experiment on guava based agri–horticultural system with an intercrop of soybean. Sole cropping of soybean resulted in maximum growth characters and significantly more seed and haulm yields than the intercropping of soybean in guava + curry leaf system.

Agroforestry is the system where both woody and non woody components occur together, a variety of positive and negative interaction occur (Garcia Barrios and Ong, 2004). However, agri–horticulture system is a part of agroforestry system where the agricultural crops are grown mainly with the fruits crops, in which the agricultural crops should be of short duration with the ability to tolerate shading effect of component tree species. Fruit tree based agroforestry system involves intentional and simultaneous association of annual or perennial crops with perennial fruit producing trees on the same

farm unit. Because of the relatively short juvenile (pre-production) phase of fruit trees, high market value of their products and the contribution of fruits to household dietary needs, fruit tree based agroforestry enjoys high popularity among resource limited producers worldwide (Bellow, 2008).

Bellow (2008) reported that the fruit tree based agroforestry systems have been only modestly studied, although they are common on small holder farms. Such systems based on apple (*Malus* spp.), peach (*Prunus* spp.) and pear (*Pyrus* spp.) are common in northwest Guatemala as low intensity home gardens and are known to increase total farm productivity in communities where farm size is a limiting factor. The complimentarily of production with the dominant maize crop, home consumption of fruit and the potential to generate additional cash on limited land holdings were identified as factors promoting adoption of fruit tree based agroforestry.

Bheemaiah and Subrahmanyam (2004) reported that the significant difference was observed in dry matter and crop growth rate and pod yield of groundnut due to cropping systems and fertilizer doses. Higher dry matter of 4162 kg ha^{-1} and almost comparable crop growth rate of 1.30 g/m^2/day was recorded under sole cropping as compared to intercropping with tamarind. Pod yields of 768 kg ha^{-1} was recorded under sole cropping which was significantly higher than the pod yields of 634 kg ha^{-1} recorded under intercropping, which might be due to minimum competitions for resources under sole cropping.

The interactions in agroforestry/agri–horticulture system can be complementary (positive), supplementary (neutral) or competitive (negative) (Van and Hairiah, 2000). The key to success in agroforestry is the minimization of negative interactions and maximization of positive interactions to get the best results (Thevathasan and Gordon, 2004).

Swamy and Puri (2005) reported the productivity of crops in agrisilviculture system. Under 5 -year old stands of *G. arborea* stands, the reduction in grain yield was maximum in urd (65%) followed by mung bean (59%) and cowpea (34%) during rainy

season. Soybean had the lowest yield losses (25% grain yield loss and 26% straw yield loss in 5-year old stands). Both straw and seed yield losses were more than two times higher in mung and urd crops compared to soybean. In the winter season, the chickpea exhibited highest yield reduction followed by linseed and mustard. The yield losses were lowest in wheat as compared to other crops. Under 5 year old stands of *G. arborea* stands, the reduction in grain yield in different crops was in the order: chickpea (36%) > linseed (16%) > mustard (14%) > wheat (7%). Similarly reduction in the straw yield was in the order: chickpea (20%) > mustard (9%) > linseed (6%) > wheat (4%). In 5 year old stands of *G. arborea*, the grain and straw yields of chickpea reduced by five times as compared to wheat.

Incorporation of green leaf manure from leguminous trees into agroforestry systems may provide a substitute for inorganic N fertilisers to enhance crop growth and yield. The different treatments included *Gliricidia sepium* trees intercropped with maize (*Zea mays* L.), with and without pigeonpea (*Cajanus cajan* L.), sole maize, sole pigeonpea, sole *Gliricidia* and a maize + pigeonpea intercrop. Uptake of N was substantially greater in the agroforestry systems (200-270 kg N ha^{-1}) than in the maize + pigeonpea and sole maize treatments (40-95 kg N ha^{-1}). Accumulation of N by maize was greater in the agroforestry systems than in sole maize and maize + pigeonpea; grain accounted for 55% of N uptake by maize in the agroforestry systems, compared to 41–47% in sole maize and maize + pigeonpea (Chirwa *et al.,* 2006).

Rebbie Harawa *et al.* (2006) revealed that maize yield varied significantly for the different cropping systems at different landscape positions. In the 2002/03 season, maize intercropped with *Gliricidia* resulted in the highest yield in the mid-slope position. In the bottom slope, the highest yield was observed with *Sesbania* relay cropping and there were no significant differences in maize yields between fields with *Sesbania* and *Tephrosia* in the mid-slope and also between *Tephrosia* and *Gliricidia* in the upper slopes. Maize yields in the 2003/04 season followed a similar pattern as the previous year's yields. In general, the yields in all agroforestry system were constantly above the monocropped maize across all three landscape positions in both seasons.

Datta and Singh (2007) studied the multipurpose tree species in an agroforestry system under subtropical humid climate in Northeast India. Direct seeded upland rice, groundnut and sesame were grown during the initial period up to 8 year of tree establishment which resulted reduction in crop productivity as compared to open field.

Awasthi and Pareek (2008) reported that the production system in arid region, which covers 12% of the country's geographical area, faces several biophysical constraints. Monoculture is often risk prone due to crop failures. Under such situation, cropping system approach integrating suitable above and ground storey crops with hardy fruit trees has been found remunerative providing food, fruit, fuel and fodder to poor farmers. The most suitable fruit and forest trees, seasonal (cereals and pulses) /medicinal/spice crops, vegetables, grasses and forages along with the cropping system models such as horti-agri, horti-pastoral and horti-agri-pastoral system. For sustainable management of arid lands and for enhancing the economic viability of the cropping system, partial shift from the existing high input requiring rotation to low input requiring system is the need of the time.

Olanyan and Fagbayide (2007) reported that sweet orange (*Citrus sinensis* L.) was intercropped between 1996 and 1999 on an *Alfisol*, at the Ibadan, Nigeria. The companion crops were maize in the early planting season, followed by cowpea in the late planting season of each year (cassava and pineapple). For comparison, there were sole plots of sweet orange, maize, cowpea, cassava, and pineapple to serve as controls. The growth of sweet orange intercropped with cassava was not as good as that of sole orange or orange intercropped with maize/cowpea and pineapple. Sweet orange in pure stands and sweet orange + maize/cowpea produced flowers 24 months after transplanting, with 75% and 87% of trees producing flowers and fruits, respectively. Fourty-two months after transplanting sweet orange + maize/cowpea and sweet orange + cassava had 1.63, 1.45, and 0.05 t ha^{-1} citrus fruit, respectively. Sweet orange intercropped with pineapple did not produce fruits.

Das *et al.* (2008) revealed that the plant height of tamarind (191.75 cm) was much influenced by turmeric intercrop which was at par with chilli and elephant foot yam. The

maximum canopy spread was recorded with tamarind + elephant foot yam (185.74 cm) in N-S direction and with tamarind + turmeric (192.43 cm) in E-W direction. In case of basal girth it was maximum in chilli (13.13 cm) and minimum with ginger (10.60 cm).

Maheswarappa (2008) studied the biomass production and sustainable productivity of coconut *(Cocus nucifera L.)* based cropping system. It was found that coconut had 31.32 per cent actual air space utilization, followed by banana *(Musa Sp.)* (7.32%), nutmeg *(Myristica fragrans)* (0.67%), pineapple *(Ananas comosus L.* Merr*)* (0.2%) and tuber crops, like amorphophallus *(Amorphophallus sp.),* colocassia *(Colocasia sp.)* and dioscorea *(Dioscorea sp.)* (0.38%) in the system. The system gave enormous quantity of recyclable biomass (9110 kg ha^{-1} to 17612 kg ha^{-1} $year^{-1}$) and which on conversion to vermicompost through *Eudrilus* sp. Contributed 70.1 to 1742.1 kg N 10.0 to 20.3 kg P and 18.0 to 36.5 kg K $year^{-1}$.

Shukla *et al.* (2008) reported that fruit species, *Annona squamosa* were not for growing in horti-pastoral system in rangelands because of their poor establishment and survival.

Kanaujia *et al*. (2009) reported that the field crops *i.e.* chickpea (*Cicer arietinum* L.), mustard (*Brassica juncea* L.) and wheat (*Triticum aestivum* L.) were sown in inter-spacing of four year old aonla as well as aonla alone. Highest yield of aonla was recorded under aonla + chickpea followed by aonla + mustard and lowest under aonla + wheat intercropping system, while the magnitude of reduction in the yield of intercrops was 18.5, 30.6 and 37.0% in chickpea, 21.7, 36.4 and 44.5% in mustard and 20.2, 34.8 and 41.4% in wheat over sole cropping during fourth, fifth and sixth year age of aonla, respectively.

Mutanal *et al*. (2009) reported that yield of finger millet was low when grown in sequence in a long term experiment on agroforestry involving arable crops (sorghum, groundnut, chilli and finger millet), horticultural crop (papaya) and pasture crops (subabul and guinea grass). Teak was planted at 10 m and 20 m apart with 2 m between plants. Finger millet yield reduction was higher *i.e.* 63.11 to 65.11 per cent in 10 m and

57.98 to 70.29 per cent in 20 m spaced teak rows compared to other crops. This was due to fast growth of teak posing severe competition with arable crops for moisture, nutrients and light. They further opined that severe yield reduction was also due to low rainfall received during the year of experimentation irrespective of the crops.

The growth and yield in perennial component were more under the multi-species cropping systems. Minimum yield was recorded in sole perennial crops. Plant height, number of branches/plant, pods/silique/fruits/plant and yield was found to be superior in multi-species cropping systems of *aonla* + *ber* + *karonda* + cluster bean + brinjal and *aonla* + *ber* + *karonda* + mothbean (*Vigna acontifolia* L.) + Indian mustard (*Brassica juncea* L.) as compared to sole cropping (Arya *et al.,* 2010).

The significant increase in equivalent yield was observed when jasmine intercropped with vegetable cowpea (45 cm x 15 cm) which recorded 5170.36 g plant^{-1} and 12925.90 kg ha^{-1}. This was comparatively followed by jasmine + small vegetable cowpea (60 cm x 15 cm) which registered 5095.35 g plant^{-1} and 12738.37 kg ha^{-1}, while the lowest yield per plant (4700.25 g plant^{-1}) and per hectare (11750.62 kg ha^{-1}) were observed in the sole jasmine (Anburani and Vidhya Priyadharshini, 2011).

Chauhan *et al.* (2011) reported that in an experiment with poplar-wheat intercropping system, the grain yield of wheat crop was maximum under control plots (5.23, 6.21 and 5.69 Mg ha^{-1}) during 2004, 2005 and 2006, respectively and it was statistically higher than the crop under block plantations. The crop yield declined significantly with advancement of age of poplar trees. The rate of decrease in grain yield of wheat crop was sharp during initial years (1st to 3rd year) and got more or less constant after 4 year old plantation. On an average, the grain yield decrease ranged from 14.55 to 64.62% under one to six year plantation as compared to the control plot. The straw yield of wheat crop was also higher in control plots during all three years (7.83, 8.23 and 8.02 Mg ha^{-1} during 2004, 2005 and 2006, respectively). The straw yield also declined with the advancement of age of poplar plantation up to 6th year.

Das *et al*. (2011) studied the aonla-based agri–horticultural systems. The results indicated that the production of fruits significantly increased due to intercrops and it was maximum in aonla in association with turmeric (13.30 tonnes ha^{-1}) followed by arbi (11.71 tonnes ha^{-1}). On the other hand, reduction in yield of intercrops was 7.5–12.0% for turmeric, 12.2–19.3% for ginger and 15.7–25.3% for arbi compared to the yield in open area without trees.

Ghosh and Hore (2011) noticed that the cropping system model (coconut + lime + ginger + okra) was found best among all. Further, planting with 25–30 g seed rhizome at 20 cm × 15 cm spacing may be recommended for ginger as intercrop in coconut plantation for maximizing the yield.

Lal *et al*. (2011) reported that in the mango cv. Mallika based agri–horti systems , Okra-toria cropping system gave maximum gross income of Rs. 26015 ha $year^{-1}$ and superseded by 298.5, 142.9, 73.1, 66.9, 26.6 and 24.3 per cent more over without intercrop, cluster bean-toria, pigeonpea, sesame-toria, blackgram-toria and cowpea-toria cropping systems, respectively.

Munde *et al.* (2011) recorded that the maximum yield (t ha^{-1}) of custard apple was recorded in treatment RDF + cowpea (3.30 t ha^{-1}) and minimum in treatment FYM alone (2.32 t ha^{-1}) in orchard of 5-7 years age group. In custard apple orchard of 10 years and above the treatment RDF + cowpea recorded maximum yield (9.55 t ha^{-1}) and minimum in treatment RDF + sorghum (8.11 t ha^{-1}). The custard apple orchard well nourished by addition of farm yard manure with recommended dose of fertilizer and intercropped by short durational leguminous crop like cowpea, fodder crop like *stylo hamata* have shown conspicuous increase in vegetative characters. The intercrop cowpea being leguminous fixed the atmospheric nitrogen in soil which was made available to the plants in addition to the dose applied per plant.

Planting Ber in bottomless old bitumin drums recorded significantly higher pooled grain yield (406.3 kg ha^{-1}) of green gram than trench in two sides of tree (387.5 kg ha^{-1}) and of mustard (1590.3 kg ha^{-1}) than Ber planted in polythene lined pits (1502.0 kg

ha^{-1}) and no tree root management (1529.5 kg ha^{-1}). Planting Ber in bottomless bitumen drums also recorded significantly higher pooled mustard straw yield (kg ha^{-1}) (4036.0) than trees planted in polythene lined pits (3932.0) and no tree root management (3939.5) but variations were at par with trees planted with trench in two sides (4039.3). No tree root management produced significantly higher Ber fruit yield (2120 kg ha^{-1}) in 1995 followed by Ber trees planted with trench in two sides (1820 kg ha^{-1}) (Om Prakash *et al.,* 2011).

Arvind Bijalwan (2012) reported that under traditional agri–horticulture system in mid hill situation of Garhwal Himalaya, the annual agriculture productivity under agri–horticulture system for summer and winter (*kharif* + rabi), when compared with control/sole agriculture system, a significant difference in productivity of agricultural crops was observed. The annual (summer and winter) economic yield of agriculture crops under agri–horticulture system as 1106 kg ha^{-1} $year^{-1}$ on northern site with a reduction of 34.56% compared to the sole agriculture crops (1720 kg $ha^{-1}\cdot year^{-1}$). The grain yield was recorded 621 kg ha^{-1} $year^{-1}$ and 485 $kg\cdot ha^{-1}$ $year^{-1}$ in summer and winter season respectively. In the southern aspect the annual economic yield of agricultural crops under agri–horticultural system recorded 1122 kg ha^{-1} $year^{-1}$ compared to 1859 kg ha^{-1} $year^{-1}$ in sole agriculture system. There was 38.29% reduction in the grain yield under agri–horticulture system compared to sole agriculture.

A synergistic effect of rhizosphere changes in intercrop influenced the performance of main crop was as evident from increase in size of the coconut from 75.21 to 93.81 cm with simultaneously increase in yield from 18 nuts $palm^{-1}$ (2812 nuts ha^{-1}) to 52 nuts $palm^{-1}$ (8125 nuts ha^{-1}). These observations supplement the fact that monoculture of coconut is less sustainable in terms of yield of main crop, besides an additional yield obtained through raising intercrop than intercropped coconut (Kikon *et al.,* 2012).

Patel and Shakhela (2012) reported that aonla based agri–horti system produced higher average fruit yields than the sole aonla trees. Aonla with pearl millet-cowpea rotation recorded the highest aonla fruit yield (7208 kg ha^{-1}) than aonla sole (6858 kg

ha^{-1}). The mean data of grain and straw yield was considerably low in intercrop as compared to sole crop.

Shirgure (2012) reported that the high soil moisture was observed in intercropping system with cotton + soyabean or cotton + black gram in the interspaces of pre-bearing and bearing mandarin improved the yield as well as sustainability of mandarin as well as the production of intercrops.

Among different intercropping systems, mango + guava + cowpea exhibited better performance which has been reflected in the form of panicle production, fruit retention, fruit weight and fruit yield of mango closely followed by mango + guava + french bean system. The mango plants, under study, however, did not exhibit any kind of variation in quality parameters such as total soluble solids and acidity in fruits. The leaf analysis result after completion of the study revealed that the N and P content of mango leaf were found to be maximum under mango + guava + cowpea intercropping system whereas the K content was estimated maximum in the mango + guava + french bean system (Swain *et al.,* 2012b).

Under mango based agri–horticulture system the mean maximum fruit yield of mango (7.02 t ha^{-1}) was harvested with cowpea-toria crop rotation followed by black gram-toria (6.59 t ha^{-1}) and minimum fruit yield (5.76 t ha^{-1}) realized with sole mango tree during first phase (1999-2005). Likewise, mean maximum fruit yield (13.71 t ha^{-1}) from mango tree was obtained in the turmeric block followed by (13.00 t ha^{-1}) in colocasia block and minimum fruit yield with sole mango tree (11.86 t ha^{-1}). The mean maximum cowpea equivalent yield (t ha^{-1}) was harvested from cowpea (1.84) followed by okra (1.21), black gram (1.11), sesame (0.68) and mean minimum with pigeon pea (0.58) (Avinash Chandra Rathore *et al.,* 2013). In another study it was reported that total dry matter production was significantly higher in sole crops and lower under intercropping at harvest (Chauhan *et al.,* 2013).

Rupinder Kaur and Sunil Puri (2013) revealed that in *Vigna mungo* productivity was almost 1.76 times more in the sole crop as compared to crop growing under tree

system; however in *Triticum aestivum* this variation was comparatively less 1.28 times more as a sole crop. Total biomass of 33.34 Mg/ha and 74.63 Mg/ha was found in *Vigna mungo* and *Triticum aestivum* respectively. Out of the total biomass of *Vigna mungo* leaf, shoot, root and pod contributed 29.06%, 41.57%, 4.94% and 24.35% respectively. Similarly for the total biomass of *Triticum aestivum* leaf, shoot, root and spikes contributed 20.91%, 28.94%, 18.98% and 31.16% respectively. It is evident that in *Vigna mungo* there is no variation in the height of plants under tree system or as a sole crop however in *Triticum aestivum* it varied and the growth was comparatively much better without tree system. No statistical variation in crop density was found between two crops growing under agroforestry system or as sole crop.

Highest total biological yield and seed yield of mung bean (1412.5 and 471.3 kg ha^{-1}, respectively) and cluster bean (1352 and 419.8 kg ha^{-1}, respectively) was recorded in intercropping with citrus. Highest leaf area plant-1and chlorophyll content in cluster bean (2.44 mg g^{-1} fresh weight) and mung bean (2.62 mg g^{-1} fresh weight) intercropped with citrus were responsible for more seed yield due to accumulation of more photosynthates in plants (Yadava *et al.,* 2013).

Abd El-Gaid *et al.* (2014) reported highest LER in 1:3 tomato and common bean planting system as 1.26 and 1.25 in first and second season, respectively. It is recommended to use this pattern to improve farmer's income and LER under New Valley conditions. Agrawal *et al.* (2010) observed maximum cauliflower yield in cauliflower + fenugreek (16.58 t ha^{-1}) intercropping system followed by cauliflower + marigold (14.80 t ha^{-1}) and minimum was noted with cauliflower sole (14.22 t ha^{-1}).

Bilas Singh *et al.* (2014) reported that wheat yield reduced by 5% to 23% in the agroforestry systems than the yield in sole crop plot. Lowest yield was in *C. mopane* + *C. myxa* combination. Fodder yield was 0.53, 0.20 and 0.07 t ha^{-1} from *C. mopane* (*cursive*), *P. cineraria* and *A. excelsa*, respectively, whereas utilizable biomass was 2.63 t ha^{-1} from *C. myxa* (*cursive*) + *P. cineraria*, 2.21 t ha^{-1} from *C. myxa* (*cursive*) + *C. mopane* and 2.18 t ha^{-1} from *Z. mauritiana* + *P. cineraria* combinations.

Bhalendra Singh Rajput *et al.* (2014) conducted a field experiment under seven years old guava based agri–horti system with three levels of row spacing (30 cm, 45 cm and 60 cm) and four level of mulching (No mulch, paddy straw mulch, green weed mulch and dust mulch). Results revealed that paddy straw mulch recorded significantly higher maize plant height (215.06 cm) with all other treatments. However, lower plant height (207.07 cm) was noticed with control treatment. Paddy straw mulch got significantly more number of leave plant^{-1} (12.71) over the dust mulch and no mulch at 80 DAS but at par with green weed mulch (12.47) and significantly higher dry matter accumulation plant^{-1} (65.33 g) with 60 cm row spacing at harvest stage. The maximum nitrogen, phosphorus and potassium uptake by grain and stover by maize was observed in the 45 cm row spacing with paddy straw mulch.

Hari Dayal *et al.* (2014) conducted an experiment where three legume crops (green gram, moth bean and cluster bean) were tested as sole crop as well as inter crops with ten years old orchard of pomegranate and aonla. The results indicated that there was no significant effect on the yield attributing parameters of the crops grown either as sole or inter crop. However, the seed yield obtained in inter cropping system was lower than that of sole cropping. The highest cluster bean equivalent seed yield (4550 kg ha^{-1}) was recorded with the inter cropping of green gram + pomegranate, which was 71.56% higher over sole green gram. Inter cropping of moth bean with pomegranate was observed next best combination for increasing cluster bean equivalent seed yield.

Subash *et al.* (2014) reported that under agri–horti system the highest number of fruit plant^{-1} (40.30), yield plant^{-1} (48.90 kg) and yield ha^{-1} (58.70 tonne) of papaya was recorded under papaya + pea followed by sole papaya, papaya + wheat, papaya + barley and lowest under papaya + mustard agri–horti systems, while the magnitude reduction in the yield of inter crops was 21.83 and 17.43% in barley, 20.48 and 17.08% in pea, 21.59 and 20.22% in mustard and 25.62 and 20.22% in wheat over sole system during 2009-10 and 2010-11, respectively.

The highest grain yield (36.0 q ha^{-1}) was obtained under open farming system (control). The reduction in grain yield was in the range of 16 to 62% under agroforestry

systems as compared to control. Poplar based agri-silvicultural system performed better as compared to other systems. Highest wheat yield was recorded in 3.0×2.5 m^2 spacing under poplar, melia and leucaena based agri-silvicultural system but in the case of eucalyptus, 3.0×2.0 m^2 spacing was the best (Sarvade *et al.,* 2014).

Bilas Singh and Singh (2015) reported that total dry biomass was highest for *P. cineraria* in both agroforestry and the control plots followed by *C. mopane* and *A. excels*. Lowest biomass was recorded for *Z. mauritiana*. Benefits of agroforestry system can be seen by greater dry biomasses of *A. excelsa, C. mopane, P. cineraria, C. myxa* and *Z. mauritiana* in agroforestry trees by 91, 78, 50, 63 and 52%, respectively than the respective control tree plots.

Ghilotia *et al.* (2015) studied that pearl millet grain yield (1568.40 kg ha^{-1}), straw yield (5192.23 kg ha^{-1}), biological yield (6760.63 kg ha^{-1}) and mean pearl millet grain equivalent yield (4817.03 kg ha^{-1}) of pearl millet and grain yield (696.14 kg ha^{-1}), straw yield (1853.29 kg/ha), biological yield (2549.43 kg ha^{-1}) of mung bean were highest under pearl millet sole and mung bean sole as compared to intercropping row ratio. Similarly, nitrogen in grain and phosphorus in grain, straw and total nitrogen and phosphorus uptake were maximum in pearl millet sole and mung bean sole as compared to other treatments. The maximum nitrogen uptake in straw (23.44 kg ha^{-1}), protein content in pearl millet (11.94%) and mung bean grain (23.82%) was observed.

Ramulu *et al.* (2015) reported that custard apple alone recorded significantly higher plant height (197.7 cm), number of branches/plant (3.3), collar stem diameter (11.3 cm), canopy spread/plant (231.33), biomass (1675.4 kg ha^{-1}), leaf litter (315.7 kg ha^{-1}), number of fruits/plant (17.8), fruit weight (395 g), fruit size (102.4 cm), fruit volume (314.1 cc), total soluble solids (32.5%) and higher fruit yield (314.1 kg ha^{-1}) followed by custard apple intercropped with foxtail millet and cowpea.

Under custard apple-based agri–horti system under rainfed condition integrated application of 50% RDF + 100% poultry manure recorded significantly higher dry matter (39.11 g $plant^{-1}$), seed yield (1002 kg ha^{-1}), straw yield (3102 kg ha^{-1}) and nutrient uptake

in grain (28.13, 3.72 and 10.06 NPK kg ha^{-1}, respectively) of green gram. Thus, combined application of inorganic fertilizer and organic manure was found to be the best for higher productivity and profitability of green gram cultivation in custard apple-based agri–horti system under rainfed condition (Rana Veer Singh *et al.,* 2015).

Nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, zinc, manganese, iron and cupper concentrations were monitored before treatment application and after treatments application. All nutrient levels in leaves of custard apple cv. Balanagar more in the treated trees than the before application of the treatments; N-2.65% (25% pruning + Potassium iodide 1%), P-0.29% (25% pruning + Orthophosphoric acid 1%), K-2.33% (25% pruning, no chemicals), Mg-0.68% (25% pruning + Orthophosphoric acid 1%), S-0.59% (25% pruning + Orthophosphoric acid 1%), Zn-9.23 ppm (50% pruning + Ethrel 2000ppm), Mn-75.85 ppm (50% pruning + Ethrel 2000ppm), Cu-28.55 ppm (25% pruning + Orthophosphoric acid 1%) but calcium 5.08% (Control (no pruning, no chemicals) and iron 335.33 ppm (Control (no pruning, no chemicals) were more in the control tress than the before application and after application of the treatment (Vinay *et al.,* 2015).

The average yield of aonla varied considerably in different cropping model systems with highest being recorded in aonla–khejri (9.5 t ha^{-1}), aonla–ber (9.0 t ha^{-1}) followed by aonla–bael (8.9 t ha^{-1}) and aonla–karonda (8.4 t ha^{-1}), while the lowest was recorded in aonla-moringa (7.8 t ha^{-1}). The higher yield in aonla involving ber and khejri could be due to synergistic crop interaction (Jatav *et al.,* 2016).

Under guava based agri–horti system, the treatment guava + cowpea and guava + French bean recorded almost similar results having maximum yield of 19.5 kg and 18.6 kg during rainy and 9.5 kg and 9.2 kg during winter season of 2009–10, respectively. Similarly, the fruit yield $tree^{-1}$ of the above treatments was also found to be highest with the values of 21.8 kg and 20.5 kg in rainy season and 12.6 kg and 12.4 kg during winter season of 2010–11. The pooled mean fruit yield of both the seasons was also noticed to be maximum in the previously mentioned treatment. The higher yield advantages under intercropping systems were mainly attributed to efficient utilization of natural resources

like solar radiation, soil moisture and nutrients because of complementary interaction between the component crops (Swain, 2016).

Ramulu *et al.* (2017) reported that the plant uptake N ranged from 21.4 kg ha^{-1} under custard apple + niger to 100.9 kg ha^{-1} under fodder maize in 2012; 25.3 kg ha^{-1} under custard apple + niger to 104.4 kg ha^{-1} under fodder maize in 2013 with mean of 48.0 and 52.7 kg ha^{-1} in the two years, respectively. Plant uptake of P ranged from 9.7 kg ha^{-1} under custard apple + foxtail millet to 24.2 kg ha^{-1} under fodder maize in 2012; 10.1 kg ha^{-1} under custard apple + foxtail millet to 25.0 kg ha^{-1} under fodder maize in 2013 with mean of 16.1 and 17.9 kg ha^{-1} in the two years, respectively. the plant uptake of K ranged from 42.9 kg ha^{-1} under custard apple + foxtail millet to 102.7 kg ha^{-1} under fodder maize in 2012, and 45.0 kg ha^{-1} under custard apple + foxtail millet to 104.7 kg ha^{-1} under fodder maize in 2013, with mean of 72.0 and 74.2 kg ha^{-1} in the two years, respectively.

Under guava based intercropping system, yield of main crop (guava) and corresponding intercrops were significantly influenced by adoption of different intercropping system. Though sole guava system recorded the highest guava production (5.10 t ha^{-1}) but the maximum system equivalent yield (20.35 t ha^{-1}) was obtained from the guava + banana intercropping system (Saswati Ghosh *et al.,* 2017).

Thus, the above reviews reveal that the agri–horti system helps in efficient land utilization, fruit, fuel, fodder and increased income per unit land and also serve as insurance against total crop failure due to aberrant weather conditions. From the above reviews, it is also observed that the crops yield and nutrient uptake by different crops was improved under agri–horticulture systems which might be due to increased nutrient dynamics under these cropping systems. Hence, it is concluded that the adoption of agri–horticulture system is the best option under dryland conditions for sustainable crop production.

2.2 Effect of agri–horticulture systems on physical, chemical and biological properties of soil

2.2.1 Physical properties

Turchenek and Oades (1979) reported that organic fractions < 2.06 g cm^{-3} from sand size separates were insoluble in alkali and had wide carbon/nitrogen ratios characteristic of plant debris. The light fractions from fine silt and coarse clay separates were more soluble in alkali but showed high ratios of humic to fulvic materials and high absorption at 280 nm. Such materials were considered to be microbial cell debris and were associated with high contents of disordered aluminium and iron oxides and expanding lattice silicates in 1 to 5 µm aggregates.

Alley cropping increased the mean aggregate diameter and water stability of soil aggregates. The mean aggregate diameter obtained from dry sieving increased from 1.3 mm of the control to 2.68 and 3.11 mm after three years in pigeon pea and *gliricidia* alley cropped plots, respectively. This is an indication of resistance to wind erosion in alley cropped plots. The wet aggregate stability which shows the resistance to erosion by water also increased in alley cropped plots. These increases were significant after three years of hedge row establishment. The increase in soil organic C in alley cropped plots contributed to the higher dry and wet aggregate stability and decreased soil bulk density. The improvement was higher in plots alley cropped with *gliricidia* than pigeon pea (Mapa and Gunasena, 1995).

A wet, nested sieve aggregate stability measurement determined that the prairie soil had a higher mean aggregate size (1.85 mm) when compared with the soil in the presence of decomposing corn (1.0 mm) or soybean (0.34 mm) residues. The results suggest that the decrease in soil stability after soybean growth was due to a decrease in the content of soil humic substances caused by the substantially lower phenolic acids content (humic acid precursors) in the soybean residue (Martens, 2000). It was also reported that stabilization is favoured through the binding action of humic substances, polysaccharides and fungal hyphae (Graham *et al.,* 2002).

Moisture retention was maximum under the tree cover of *Morus alba* but low in soils under other trees (*Acacia nilotica*, *Leucaena leucocephala*, *Tectona grandis* and *Azadirachta indica*) (Datta and Dhiman, 2001). Kukal and Manmeetkaur (2003) reported that pasture and forest soils retained more water at field capacity than agricultural land. This was attributed to better aggregation due to higher organic matter content in forest soils. The water stable aggregates were maximum (94.8%) in pasture soils followed by 42.3% in forest soils and 40.4% in agricultural soils.

The average 60-min cumulative infiltration was five times greater under the riparian buffers than under the cultivated field and pasture. Cumulative infiltration in the multi-species riparian buffer was in the order of silver maple > grass filter > switchgrass. Cumulative infiltration did not differ significantly among corn and soybean crop fields and the pasture. Soil bulk densities under the multi-species buffer vegetation were significantly smaller than in the crop fields and the pasture. Other measured parameters did not show consistent trends (Bharati *et al.,* 2002).

Franzluebbers (2002) evaluated the water infiltration and soil structure relation to OM and its stratification with depth and found that short-term soil disturbance of previously stratified soil led to uniform distribution of soil organic carbon, reduced soil BD, and increased water retention.

Sushil Kumar *et al.,* (2002) reported that aggregates having diameter greater than 0.25 mm were more in the surface soil under all the land use classes (cultivated soil, orchards and forest land use).

Korwar *et al.* (2006) reported that, the application of vermicompost, FYM, and sunnhemp (*Crotalaria juncea* L.) as green manure (GM) along with chemical fertilizers resulted in the maintenance of the physical, chemical and biological properties of soil. Therefore, sustained efforts are needed to improve and maintain this most important natural resource base-the soil through judicious integration of mineral fertilizers, organic and GM and bio fertilizers so that, it nourishes intensive cropping without being irreversibly damaged in the process.

Sultani *et al*. (2007) observed 7% reduction in soil bulk density value and an increase of 11% in total soil porosity and available water content in plots where *sesbania* was incorporated as green manuring crop. The order of effectiveness in improving bulk density, macro and mesopores was: *sesbania* > cluster bean > rice bean. Swain and Patro (2007) reported a decrease in bulk density and increase in N and P availability of soil due to increase in the soil organic matter content while studying the effects of different intercropping in mango orchards.

Hatti *et al*. (2008) revealed that application of balanced fertilizer along with manure (NPKM) or lime (NPKL) improved soil aggregation, soil water retention, microporosity and available water capacity and reduced bulk density of the soil in 0 to 30 cm depth over control. In contrast, soil aggregate stability, microporosity and available water capacity were significantly lower in the nitrogen alone treated plots than that in control and also suggests that soil management practices in acidic *Alfisols* should include integrated use of mineral fertilizer and organic manure or lime to maintain the organic carbon status and physical environment of soil.

Humic acid and inorganics play important role in stabilization of clay microstructure (<2 µm diameter), whereas micro- and macroaggregates are stabilized by bacteria, fungi, microbial derived substances, plant roots and their exudates, which are directly and/or indirectly influenced by amount of organic matter present in the soil (Aparicio and Costa, 2007). The percentage of water stable aggregate (WSA) was significantly different between soils from the buffer and crop treatments. The grass buffer (GB) and agroforestry buffer (AG) areas had nearly twice (1.94) the stable aggregates compared with crop areas. The proportion of WSA among the four treatments was highest in grass waterways (GWW) with 19.97±1.75, which was significantly different from the other three treatments; the crop area had the lowest WSA at 7.68±1.24. The difference between GB and AG was not significant. The percentage of WSA was significantly different among all three landscape positions. The lower and middle positions contained higher percentages of WSA with 17.30%±1.53% and 13.03%±1.53%, respectively. The upper landscape position, with the lowest percentage of WSA, contained 8.76%±1.54% (Ranjith *et al.,* 2008).

Gol (2009) reported that significantly higher values of saturated hydraulic conductivity in natural forest top soil (82.4 cm^{-1} h^{-1}) compared to grassland soils (8.4 cm^{-1} h^{-1}) hazelnut garden soils (11.5 cm^{-1} h^{-1}) and corn filed soils (30.0 cm^{-1} h^{-1}). Similarly, it was observed that greater percentage of water stable aggregates is the pasture and forest soils than in cultivated soils.

Gupta *et al.* (2009) reported the effects of SOC and aggregation under poplar-based agroforestry system in relation to tree age and soil type. It was observed that the mean weight diameter (MWD) of soil aggregates increased by 3.2, 7.3 and 13.3 times in soils with 1, 3 and 6 year old plantation, respectively as compared to sole crop. The increase in MWD was however higher in loamy sand than sandy clay loam soil.

Bulk density of the profile soil samples ranged from 1.48 to 1.67 Mg m^{-3} and bulk density increased with increases depth of soils in all land use systems (Agriculture, horticulture, silviculture and current fallow land use system) due to low organic matter content of lower layers and compaction from the pressure of the upper layer (Gurumurthy *et al.,* 2009). Mousavi *et al.* (2009) also reported increase in bulk density with depth in case of paddy.

Benbi and Senapati (2010) studied the impact of continuous application of rice straw and farmyard manure (FYM) either alone or in conjunction with inorganic fertilizers on aggregate stability and distribution of carbon and nitrogen in different aggregate fractions after 7 years of rice–wheat cropping on a sandy loam soil. Macroaggregates (>0.25 mm) constituted 32.5–54.5% of total water stable aggregates (WSA) and were linearly related (R^2 = 0.69) to soil organic carbon content. The addition of rice straw and FYM significantly improved the formation of macroaggregates with a concomitant decrease in the proportion of microaggregates at all the three sampling depths (0–5, 5–10 and 10–15 cm). Macroaggregates had higher C and N density as compared to microaggregates.

The greatest soil bulk density was observed in cultivated field followed by pasture and forest lands by Kizilkaya and Dengiz (2010). This difference was ascribed to the compaction of the surface soil due to overgrazing and intensive field traffic.

Soil aggregate stability (SAS) was quite low under bare fallow land and cropping land soils, in comparison with the 4 forest communities. The three main fractions of soil aggregates, obtained by ultrasonic fractionation, were <63 μm, 63–100 μm and 100–250 μm, which represented approximately 60%, 10% and 10%, respectively. In all land uses, macro-aggregates, 1000–630 μm >630–250 μm had a higher organic carbon content than micro-aggregates, 250–100μm>100–63μm>63μm. In comparison to cropland and bare fallow land, forest and artificial shrub can protect and enhance the organic carbon, total N and soil aggregate stability. The higher C:N ratio of macro-aggregate fractions indicates a rapid turnover of soil organic carbon in the top soil of forest sites and even on bare fallow and crop land. The narrow range of C:N ratio in micro-aggregates indicates that soil organic carbon in micro-aggregates is more stable than that in the macro-aggregates. It was concluded that revegetation of eroded soils accelerates soil remediation and rehabilitation (Shaoshan An *et al.,* 2010).

Saha *et al.* (2011) determined the water stability aggregates (WSA) and they found that it was highest in surface soils of grassland followed by forest, agricultural and eroded lands. The WSA >2mm were highest in grassland and lowest in eroded lands. On the other hand, the eroded soils had 2.2, 7.4 and 3.4 times higher amount of microaggregates (WSA<0.25mm) than agriculture, forest and grassland soils, respectively.

For both *Pinus rigida* and *Larix kaempferi* plantations, small macroaggregate accounted for most of the weight proportion, from 50.6% to 90.1%, in the whole soil samples. The mean weight proportion of large macroaggregate, small macroaggregate, microaggregate and silt-plus-clay were 9.8%, 65.3%, 19.7%, and 5.3% in the *Pinus rigida* plantation and 12.0%, 74.0%, 12.1% and 3.9% in the *Larix kaempferi* plantation, respectively. In both plantations, the weight proportion of large macroaggregate was

higher in the surface soil than in the deep soil and the weight proportions of microaggregate and silt-plus-clay tended to increase with soil depth (Park *et al.,* 2012).

Sandeep Kumar *et al.* (2012) measured and reported that quasi-steady state infiltration rates (*qs*) and field-saturated hydraulic conductivity (K_{fs}) for grass buffers (GB) were about 31 and 46 times higher as compared to pasture treatments, respectively. Green Ampt and Parlange models appeared to fit measured data with r^2 values ranging from 0.91 to 0.98. The *qs* (measured with ponded method) in the first year for the GB treatment was the highest (221 mm h^{-1}) and for the continuously stocked (CP) treatment was the lowest (3.7 mm h^{-1}). For both years, estimated sorptivity (*S*) and saturated hydraulic conductivity (*Ks*) parameters were higher for buffer areas compared to the stocked pasture areas.

A study revealed that the mango + guava + cowpea and mango + guava + french bean systems resulted significant improvement in the bulk density of soil to 1.27 g cc^{-1} and 1.28 g cc^{-1} within 0-15 cm deep and to 1.29 g cc^{-1} and 1.30 g cc^{-1} within 15-30 cm deep against 1.35 g cc^{-1} and 1.36 g cc^{-1} under the control plot, mango + guava + no intercrop. Among different treatments, the mango + guava + cowpea system increased the water-holding capacity of soil to 36.6% and 32.3% as compared to 30.1% and 28.3% in control, mango + guava system without intercropping within depths of 0-15 and 15-30 cm. The moisture retention under different intercropping was in the order of cowpea > French bean >mango–ginger=paddy=turmeric >ragi >niger> tomato >no intercropping (control) (Swain *et al.,* 2012a).

Brar *et al.* (2013) reported that in a long term study on use of inorganic fertilizers and organic manures in rice-wheat system, the bulk density decreased with fertilization. The balanced fertilizer application (100% NPK) integrated with organic manure (FYM) significantly decreased the bulk density of surface soil over the imbalanced fertilizer treatment. However, at lower soil depths the effects of fertilization on bulk density were non-significant, though there was an increasing trend with increase in soil depth.

Jaqueline Dalla Rosa *et al.* (2013) reported that the soil physical properties in the vine rows were not influenced by cover crops and were similar to the native forest, with good quality of the soil structure. In the inter-rows, however, there was a reduction in biopores, macroporosity, total porosity and an increase in soil density, related to the compaction of the surface soil layer. The mechanical mowing system increased soil aggregate stability compared to the desiccation with herbicide system.

Sierra *et al.* (2013) reported that soil bulk density increased in samples according to the soil depth, although the increment was more pronounced in corn crop than in poplar plantation soils because in corn continuous tilling increased porosity in the surface layer but compaction in sub-surface layers.

Devine *et al.* (2014) reported that the aggregate stability decreased significantly from forest succession (FS) and no-till (NT) to conventional tillage (CT) in the upper 5 cm. In the 5-28 cm layers FS soil was significantly more stable than both NT and CT. This response can also be seen as: (i) a higher percentage of wet-sieved, large macroaggregates (>2000 mm) in the FS and NT soils from 0-5 cm compared to CT, (ii) more large macroaggregates in FS from 15-28 cm compared to both CT and NT, and (iii) a higher proportion of fines (<53 mm) in 0-15 cm under CT compared to both NT and FS.

Ashim Datta *et al.* (2015) reported that among four horticultural land uses namely, guava (*Psidium guajava*), litchi (*Litchi chinensis*), mango (*Mangifera indica*) and jamun (*Syzygium cumini*), the lowest BD was associated with guava (1.45 Mg m^{-3}) followed by mango (1.57 Mg m^{-3}) ≤ jamun (1.57 Mg m^{-3}) < litchi (1.62 Mg m^{-3}). Soil BD increased with depth increment in all the land uses due to low organic matter content and compaction from the pressure of the upper layers. In all the land uses, pH significantly increased along depth with an exception in soils under mango and litchi land uses where immediate increment in soil depth from 20 to 40 cm, soil pH slightly decreased and then again increased. For all cases, EC was much less than the critical level (4.0 dS m^{-1}) and showed low salt content in the soils. The EC of the soil increased from 0.07 to 0.16 dS m^{-1} with increasing depth under guava plantation.

In an experiment containing hybrid walnuts + wheat and control plot (wheat as sole crop), clay, silt and sand profiles were very similar at both plots. Soil texture was homogeneous in the first 50 cm. Clay and silt contents linearly increased till 100 cm soil depth to reach about 325 g kg^{-1} and 575 g kg^{-1} respectively, while sand content decreased. Soil bulk densities were significantly higher in the control plot than in the tree row at all depths except for 30–50 and 140–160 cm and higher than in the inter-row, except for 10–30 and below 140 cm depth. In the agroforestry system, soil bulk densities were higher in the inter-row than in the tree row for 0–10 and 10–30 cm (Remi Cardinael *et al.,* 2015).

Among three plant systems: a walnut (*Juglans regia*) monoculture system (JRMS), a wheat (*Triticum aestivum*) monoculture system (TAMS), and a walnut wheat alley cropping system (JTACS) over a period of 11 years, the JTACS facilitated infiltration and its infiltration rate temporal distribution showed a stronger relationship coupled with the rainfall temporal distribution compared with the two monoculture systems during the growing season. However, the effect of JTACS on the infiltration capacity was only significant in shallow soil layer, *i.e.,* the 0–40 cm soil depth. Within JTACS, the speed of the wetting front's downward movement was significantly faster than that in the two monoculture systems when the amount of rainfall and its intensity were higher. The soil infiltration rate was improved and the two peaks of soil infiltration rate temporal distribution and the rainfall temporal distribution coupled in rainy season in the alley cropping system, which has an important significance in soil and water conservation (Wang *et al.,* 2015).

The soil under poplar plantations was sandy loam in texture with average sand and clay content varying from 56.5 to 65.0 and 15.4 to 17.5%, respectively for the surface soil layer. Whereas under rice- wheat sequence, the texture was sandy clay loam with average sand and clay content of 54.9 and 25.62%, respectively. The average bulk density ranged from 1.50 to 1.53, 1.56 to 1.70 and 1.47 to 1.68 Mg m^{-3} under different treatments in the 0-15, 15-30 and 30-45 cm soil depth, respectively (Shehnaz Sharma *et al.,* 2015).

Fabien Ferchaud *et al.* (2016) reported that bulk densities measured in spring 2006 were 1.39 g cm^{-3} on average in the 0-40 cm layer of soil under perennial and annual bioenergy crops. In 2011 and 2012, bulk densities varied significantly with rotation, but not with nitrogen fertilization. The bulk density in the 0-40 cm layer was higher for perennial than for other crops (1.49 vs. 1.44 g cm^{-3}, respectively), probably due to soil compaction occurring during the harvest of perennial crops (particularly for late harvest) and absence of soil tillage. No significant difference between treatments was found below 30 cm. In the 40-60 cm layer, the mean bulk density was 1.57 g cm^{-3}.

Jatav *et al.* (2016) reported that maximum water holding capacity at 0.33 and 6% bar was observed under aonla + ber (2.28 and 1.10%) followed by aonla + khejri (2.07 and 1.03%), aonla + bael (2.44 and 0.99%), aonla + karonda (1.76 and 0.61%) and aonla + moringa (1.84 and 0.56%). Maximum mean of available water (10 to 100 cm depth) was found in aonla + ber (7.43%) followed by aonla + khejri (6.6%), aonla + bael (4.14%) and aonla + karonda (4.05%). aonla + khejri and aonla + ber showed maximum water holding capacity might be due to improved soil organic matter and better soil aggregation under these systems.

Swain (2016) revealed that the guava + cowpea and guava + french bean systems resulted significant improvement in the bulk density of soil to 1.28 g cc^{-1} and 1.29 g cc^{-1} within 0–15 cm and to 1.30 g cc^{-1} and 1.31 g cc^{-1} within 15-30 cm of soil depth as against 1.36 g cc^{-1} and 1.37 g cc^{-1} under control plot *i.e.,* guava + no intercrop. Among different treatments, guava + cowpea system increased the water holding capacity of soil to 34.5% and 30.1% as against 28.0% and 26.1% in control *i.e.,* guava system without intercropping within 0-15 and 15-30 cm soil depths. The moisture retention under different intercropping was in the order of cowpea >French bean>mango=ginger= paddy=turmeric >ragi >niger>tomato >no intercropping (Control). The addition and recycling of biomass under intercropping systems helped in improving bulk density and water holding capacity of the soil.

Chunfeng Chen *et al.* (2017) reported that rubber-based agroforestry ecosystems had a significant main treatment effect on the mean weight diameter (MWD) among the

0–5, 5–15, and 15–30 cm sampling depths. The MWD was significantly greater under rubber-based agroforestry systems than that under the rubber monoculture (Rm) system at a 0–5 cm depth. The MWD values with *H. brasiliensis – C. Arabica* (CAAs), *H. brasiliensis – T. cacao* (TCAs), *H. brasiliensis – F. macrophylla* (FMAs) and *H. brasiliensis-D. cochinchinensis* (DCAs) were 22.52%, 120.07%, 70.9% and 102.62% higher than that with Rm, respectively. In the depths of 5–15 and 15–30 cm, the MWD was significantly higher under TCAs and DCAs than that under Rm, however, no significant differences were found with CAAs and FMAs. The MWD increased gradually with the soil layer depth with four treatments and the differences with rubber-based agroforestry systems were obvious, especially in the 0–5 cm layer.

Dhaliwal *et al.* (2017) reported that the stability index was highest in agroforestry system under fine textured soil (0.223 J kg^{-1}) and lowest in maize-wheat system under coarse textured soils (0.086 J kg^{-1}) in surface soils. The cropping system and soil particle fractions significantly influenced the aggregate stability. Single raindrop simulator was used to study the impact of raindrops on the aggregate stability under different textured soil and cropping systems.

Soils from cropland and forest land use systems at Takarla contained more clay and silt as compared to those in the other two systems. A significant trend between aggregate stability and organic C content was noted in the highly aggregated and pasture soils, but the aggregate-C trend was not evident in the cropped soil. At Takarla, the soil bulk density values observed in the cropland and grassland were 1.66 and 1.51 g cm^{-1} respectively. These are high as compared to other systems because of impact of machinery in the cropland. At Mukerian, bulk density values of cropland and grassland were 1.62 and 1.56 g cm^{-1}, respectively. An increase in bulk density with depth has also been observed by different workers under different soil types (Rajwinder Kaur and Bhat, 2017).

Purnananda *et al.* (2017) conducted an experiment under different horticultural land use systems. According to them the texture of soils from coconut and areca nut land use system were sandy clay, sandy clay loam and sandy loam and in pomegranate,

banana, onion, chilli land use system texture observed were clay, clay loam, sandy loam and sandy clay loam. Higher bulk density was recorded in all the land use systems. Among them arecanut land use system was recorded highest bulk density (1.68 Mg m^{-3}) and lowest bulk density under banana land use system (1.30 Mg m^{-3}).

Ramulu *et al.* (2017) reported that the water holding capacity (WHC) under custard apple based agri–horti system ranged from 33.6% under foxtail millet and custard apple to 40.7% under custard apple + cowpea in 2012; 34.0% under custard apple to 41.3% under custard apple + cowpea in 2013 with a mean of 36.0 and 36.6% in 2012 and 2013, respectively. The mean WHC over years was significantly lower in the sole custard apple (33.8%) compared to the other systems. The infiltration rate ranged from 11.2 cm hr^{-1} under custard apple to 32.4 cm hr^{-1} under custard apple + cowpea in 2012; and 12.2 cm hr^{-1} under custard apple to 33.8 cm hr^{-1} under custard apple + cowpea in 2013 with mean of 19.9 and 20.7 cm hr^{-1} in 2012 and 2013, respectively. At 0–15 cm soil depth, the bulk density ranged from 1.41 g cc^{-1} under custard apple + cowpea to 1.59 g cc^{-1} under custard apple in 2012; 1.41 g cc^{-1} under custard apple + cowpea and cowpea to 1.58 g cc^{-1} under custard apple in 2013 with a mean bulk density of 1.47 g cc^{-1} in both years.

Saswati Ghosh *et al.* (2017) studied the guava based intercropping system and revealed that the guava + banana and guava + eggplant systems resulted in significant improvement in the bulk density of soil to 1.28 g cc^{-1} and 1.30 g cc^{-1} within 0–15 cm, 1.30 g cc^{-1} and 1.35 g cc^{-1} within 15–30 cm and 1.34 g cc^{-1} ^{3} and 1.36 g cc^{-1} within 30–45 cm of soil depth as against 1.35 g cc^{-1} , 1.37 g cc^{-1} and 1.40 g cc^{-1} under control plot *i.e.,* guava + no intercrop. Addition of organic biomass by adoption of intercrops resulted in better aggregation properties of the soil which ultimately helped to improve soil bulk density. Among different treatments, guava + banana and guava + eggplant based intercropping system increased the water holding capacity of soil to as compared to control *i.e.,* guava system without intercropping within 0–15, 15–30 and 30–45 cm soil depths.

In different fruit based agroforestry systems the bulk density was decreased under fruit based agroforestry as compared to initial value (before intercropping) in all soil

depths. It was observed that at initial (before intercropping) the soil bulk density (g cc^{-1}) was found at soil depth 0–15 cm, 15–30 cm and 30–60 cm were 1.64, 1.96 and 2.24 gm/cm^3, respectively. The decrease in bulk density is corroborating with tillage operation during crop cultivation during the intercropping of agroforestry system. The result revealed that at initial (before intercropping) the soil water holding capacity (%) was higher at surface soil depth (0–15 cm) (33.01%) and decreases as the increase in soil depth and increased significantly. At soil depth 0–15cm higher water holding capacity (%) was recorded in *Alnus nepalensis* + *Citrus reticulata* + pea (*kharif*) + mustard (*rabi*) (39.44 %) intercrops treatment followed by *Alnus nepalensis* + *Pyrus communis* + pea (*kharif*) + mustard (*rabi*) (38.15%) intercrops treatment and was lowest in sole fruit trees (35.43 and 34.10%) respectively. This might be due to more litter production and subsequent litter decomposition under trees favouring higher soil moisture retention capacity (Subba and Dhara, 2017).

Among four major land uses (cropland, grassland, area exclosure, eucalyptus plantation) The soil aggregate stability was significantly higher in the eucalyptus plantation (82%) than in the other land use types, except in the exclosure (72%) and the lowest value was found in the cropland soil (41%). The SAS of the natural forest, area exclosure and grassland were not statistically significantly different. The study highlights that the conversion of natural forest to cropland results in decline of soil quality and aggregate stability. However, compared to cropland, application of area exclosure and afforestation on degraded lands restores soil quality and aggregate stability (Yoseph *et al.,* 2017).

Anand Salve *et al.* (2018) revealed that bulk density (1.34 g cm^{-3}) was higher in Agri-silviculture system. Maximum bulk density (1.47 g cm^{-3}) was recorded at 15–30 cm depth whereas minimum bulk density (1.20 g cm^{-3}) observed at 0–15 cm depth. Particle density (2.49 g cm^{-3}) was significantly higher in agri–horticulture system while significantly higher at 0–15 cm depth (2.48 g cm^{-3}). The pore space per cent was significantly higher in agri–silviculture system (46.99%) and at surface soil (48.90 %).

Dario Fornara *et al.* (2018) found that mean bulk density of the soil samples collected at a depth of 0–20 cm was significantly higher in the silvopasture (1.13 g cm^{-3}) than in the grassland (1.02 g cm^{-3}) and the woodland (0.99 g cm^{-3}) plots. Overall across all land uses bulk density at a depth of 0–10 cm (1.02 g cm^{-3}) was lower than that at 10–20 cm (1.08 g cm^{-3}).

Kirtika Padalia *et al.* (2018) reported that the highest sand percentage was observed in home gardens (HG), silt in agriculturally discarded land (ADL) and clay in crop fields with multiple tree species (C + mT). Compared to uncultivated land (1.05 g/cm^{-3}), BD increased up to 12% in cultivated land (1.27 g/cm^{-3}), indicating that cultivation increased the bulk density. The porosity ranged from 52.07 crop fields with single tree species (C + sT) to 60.34% (ADL) while water holding capacity ranged from 31.45 (crop fields without tree/shrub species, OC) to 46.71 (C + mT). The soil temperature was speckled between 23.4°C (C + sT) and 25.1°C (OC), while the soil moisture varied from 4.80% (OC) to 7.70% (C + mT).

Rocha Junior *et al.* (2018) showed that the values of aggregation index were higher in the pasture with soil aggregates class higher than 2 mm. The forestry fragment showed the highest homogeneity of aggregates between the soil aggregates, however, the lowest values of the geometric mean diameter (GMD) were found in this management. In the superficial layer (0.00–0.10 m) the agroforestry system showed the highest value of GMD with 2.78 mm, while in the sub-surface layers the highest values were obtained in the pasture.

2.2.2 Chemical properties

Swarup (1984) reported that the incorporation of organic manures brought about a remarkable improvement in the availability of native and micronutrient cation in soil form stable complexes with organic ligands that decrease their susceptibility to adsorption, fixation or precipitation in the soil.

A mixed farming experiment results on soil properties showed that there was an increase in maximum water holding capacity and porosity and decrease in bulk density.

There was a build–up of organic carbon, N, P, K and Fe status, whereas there was decrease in the available Ca, Mg, Mn Cu and Zn. Leaf nutrient status of coconut palms was increased resulting in increased nut yield (Maheswarappa *et al.,* 1998).

In another study Santhy *et al*. (1998) revealed that continuous cropping and fertilization had a deleterious effect on total K level of soil. They further reported that application of K at 150 per cent of optimal level could maintain the initial status of total K.

Gupta *et al*. (2000) studied the changes in soil fertility status as a consequence of differential levels of urea and manure addition to rice or wheat alone or to both the crops after the completion of two cycles of rice-wheat sequence in a *Typic ustipsamment*. The increase in O.C. status was directly related with the quantity of urea and manures addition. Available N status increased with increasing N addition. Combined application of urea and FYM significantly enhanced O.C. and available N status over similar N addition through urea alone. Available P and K content of the soil decreased with successive rise in levels of N addition through urea whereas the status of these nutrients increased in plots receiving combined application of urea and manures. DTPA–extractable Fe, Mn and Cu decreased from their respective initial status. The magnitude of decline of these micro-nutrients narrowed down when 30 or 60 kg N was supplemented through manures. More so with FYM. On the other hand, available Zn status increased from its initial status since both the crops received basal dressings of $ZnSO_4$.

Pandey *et al.* (2000) reported the influence of three tree canopy positions, *viz.,* mid canopy, canopy edge and canopy gap of *Acacia nilotica* (> 12 years) and found that soil organic C, total N, total P, mineral N (NO_3^-–N and NH_4^+–N) and P were greater under mid canopy and canopy edge positions compared to canopy gap. Soil organic C and N pool sizes were maximum in surface layer and declined with the depth. But, total and mineral P contents remained uniform across the depths. Further, they concluded that *Acacia nilotica* increased soil organic C under its canopy, probably through organic matter inputs via leaf litter and dead roots, which bind soil particles and reduce runoff.

Soil pH was lower by 7.71% under the mid canopy than that under canopy gap. Soil pH did not vary significantly with depth under mid canopy but it varied among the depths under the other canopy positions.

There was an increase in the concentration of Cu, Zn, Mn and Fe in the soil planted with *Acacia tortilis*. The increase in the concentration of these elements was positively correlated with the age of the plantations (Singh *et al.,* 2002). Increase in organic carbon contents of mango orchard soil due to intercropping practices in mango orchard have been reported by Nath *et al.* (2003)

Ramesh and Chandrasekaran (2004) revealed that humic and fulvic acid fraction were improved in rice - rice cropping system encompassing green manure as intercropping with different organics. They reported that among the organics magnitude of increase in control. They also opined that GM contains polyphenols, humic acid fraction was more in FYM followed by poultry manure as compared to which might have combined with GM protein to render residue recalcitrant to microbial attack and provided fast route to increased SOC.

Nuruzzaman *et al.* (2005) conducted a pot experiment to compare phosphorus acquisition of three legume species *viz.,* Field pea (*Pisum sativum* L.), faba bean (*Vicia faba* L.), white lupin (*Lupinus albus* L.) with that of wheat, and to determine whether the legume crops influence growth and P uptake of a subsequent wheat crop. Results showed that Field pea and white lupin had large amounts of rhizosphere carboxylates, whereas wheat and faba bean had negligible amounts in all three soils at both P levels. Wheat grew better after legumes than after wheat in all three soils. The effect of the previous plant species was greater when these previous species had received P fertiliser. All the legumes increased plant biomass of subsequent wheat significantly over the unplanted pots in all the soils. Faba bean was unparalleled in promoting subsequent wheat growth on all fertilised soils. This experiment clearly demonstrated a residual benefit of the legume crops on the growth of the subsequent wheat crop due to enhanced P uptake. Faba bean appeared to be a suitable P–mobilising legume crop plant for use in rotations with wheat.

Chirwa *et al.* (2006) reported that among different treatments, including *Gliricidia sepium* trees intercropped with maize (*Zea mays* L.), with and without pigeonpea (*Cajanus cajan* L.), sole maize, sole pigeonpea, sole *gliricidia* and a maize + pigeonpea intercrop, total soil mineral N content (NO_3^-+NH_4^+) was greatest in the agroforestry systems. Pre-season soil mineral N content in the 0-20 cm horizon was greater in treatments containing trees (<85 kg N ha^{-1}) than in those without (<60 kg ha^{-1}); however, soil mineral N content declined rapidly during the cropping season. Soil mineral N levels and maize yields were similar in the *gliricidia* + maize and *gliricidia* + maize + pigeonpea treatments, implying that addition of pigeonpea to the tree-based system provided no additional improvement in soil fertility.

Babu *et al.,* (2007) studied the effect of integrated use of organic and inorganic fertilizers on soil properties and yield of sugarcane reported that there was a slight reduction in soil pH and increase in electrical conductivity with the application of organic manures. At the end of ratoon crop, the increase in available N and Ca was maximum (38.2% and 24.4%) with the application of FYM whereas the application of poultry manure resulted in the highest increase in available P (122.2%), K (23.6%) and magnesium (47.4%) over the initial soil values. Application of poultry manure along with inorganic fertilizers resulted in higher cane yield in plant crop whereas, FYM along with inorganic fertilizers resulted in the highest cane yield in ratoon crop.

Kishore (2007) reported that the main planting system followed were top hill arecanut (*Areca catechu*), middle hill banana (*Musa paradisiaca*), lower hill litchi (*Litchi chinensis*) and all fruit trees were grown as rainfed. The Most of the soils tested were low in available N, ranging from 76 to 283 kg ha^{-1}, Available P varied from 9.3 to 29.4 kg^{-1} and available potassium status, ranging from 69 to 219 kg^{-1} in soybean cultivation.

Olanyan and Fagbayide (2007) studied the effects of sweet orange based intercropping system on the soil showed that pH decreased by 2.17, which was a 5.2% decrease for all the cropping systems after three years of continuous cropping. There was a build up of nitrogen and organic carbon in the soil for all the intercrops after the third year of the study. The cropping mixture of sweet orange + maize/cowpea and sole sweet

orange had the highest N value of 0.70 g N kg^{-1} soil as compared to 0.30 g N kg^{-1} pre-planting. Sweet orange leaf analysis for N in all the treatments showed that leaf N was higher than the 2.5–2.7% optimum level, except for citrus intercropped with cassava, which had a leaf N concentration of 2.36%. Sweet orange intercropped with maize/cowpea had the highest phosphorus level of 0.17%, followed by sole sweet orange, while sweet orange intercropped with cassava or pineapple had the lowest P values. Potassium was in the adequate range in the sweet orange leaves for all the cropping systems. The nutrient dynamics were results of the interaction among cropping systems, soil depth, and cropping cycle. Maize intercropped in the early planting season followed by cowpea in the late season was the most compatible crop with sweet orange in terms of fruit yield.

In a study on short and medium term poplar plantation in soil, Moscatelli (2008) observed a significant increase of cation exchange capacity with age of poplar plantation. Sartori *et al.* (2007) reported that along a chronosequence of poplar plantation in USA soils were more acidic under second rotation stands and remained the same with increase in soil depth, whereas in other land uses the pH increased with soil depth from acidic in the surface to near neutral values in deeper layers. The cation exchange capacity did not differ significantly under different land use systems but decreased with depth.

Yadav *et al.* (2008) carried out a field experiment to study litter fall production, decay rates, release of nutrients and consequent changes in soil physicochemical properties under crowns of four multipurpose tree species in irrigated conditions in farm fields. The species were *Prosopis cineraria*, *Dalbergia sissoo*, *Acacia nilotica* and *Acacia leucophloea*. Results suggested that there was significant build-up of soil organic carbon and available NPK in the agri–silvicultural systems but also a decrease in soil pH. Build-up in soil fertility was significantly correlated with litter fall and soil improvement was greatest under *P. cineraria*.

Arevalo *et al.* (2009) stated that the increase in exchangeable Ca and Mg with soil depth were likely to have been brought about by weathering and leaching. Constant mixing of the soil by ploughing and disking of the soil surface release more exchangeable

Ca and Mg, which are leached to subsurface layers with precipitation and infiltration. The high Ca and Mg concentrations are consistent with high pH in 20–50 cm soil layer than at 0–20 cm soil layer.

Burman *et al.* (2009) reported increasing trend for pH of soil with increasing distance from the trees. The production of weak acids from the composition of tree litter resulted in lowering of pH. Organic carbon decreased with increasing distance from the trees. Organic carbon status of the soil was higher on northern side of the tree as compared to southern side. This was due to more shading effect of trees on northern side. The decreasing trend was observed for available N, P and K with the increasing distance from the trees. The higher fertility level nearer to tree *i.e.* under canopy was due to constant addition of tree leaf litter and its decomposition.

Sharma *et al.* (2009) reported that among the different land-use systems, agroforestry system resulted in the highest pH (7.5), CEC (13.6 cmol kg^{-1}), and organic carbon content (9.6 g kg^{-1}). Exchangeable nutrient cations [calcium, magnesium and sodium] and total nutrients [nitrogen, phosphorus, potassium, Ca, Mg, copper, manganese, zinc and iron were also significantly influenced by land-use systems. Improvement in nutrient status of soil due to tree based intercropping systems was also reported by Gupta and Sharma (2009).

Rai *et al*. (2009) revealed that the multipurpose trees in silvi–pastural system decreased soil pH as compared to control. Change in soil pH under silvi–pastural system compared to control due to combined effects of decay of multipurpose tree litter, sloughing off roots and changed microclimate. Change in soil organic carbon increased under silvi–pastural system compared to control was due to combined effects of decay of multipurpose tree litter, sloughing off roots and changed microclimate. Increased total nitrogen and available potassium in soil compared to control due to combined effects of decay of multipurpose tree litter, sloughing off roots and changed microclimate.

Sanjib Kumar *et al.* (2009) studied the effect of continuous cropping with maize and wheat on soil characteristics and various forms of micronutrient cations in an

Inceptisol over the years in an on–going long-term experiment in New Delhi, India. The results showed that DTPA–extractable Fe and Mn (but not Zn and Cu) in soil declined from their respective initial (1971) values as a result of intensive cropping for more than three decades. It also resulted in a decrease in the concentrations of all the four metallic cations bound to organic matter, in addition to Fe and Zn, associated with carbonates in all the treatments in surface soil.

In a study on the release of nutrients from poplar litterfall in an agroforestry system under subtropical conditions, Singh (2009) reported that a total of 20.1 Mg ha^{-1} litterfall was added during six-year plantation period. A significant increase in nutrient return through litterfall with increase in age of plantation was observed. Quantities of 176, 21.7, 133, 368 and 55.4 kg/ha of N, P, K, Ca and S were added to the soil through litter fall in six years. The total quantities of nutrients returned to the soil varied in the order Ca>N>K>S>P which was also similar to the concentration of nutrients in the falling litter.

Michel (2010) reported that the natural forest (secondary forest and primary forest) and multi specific planted trees lands had significantly greater mineralizable soil C and N in soil surface than other land use investigated. Similarly, the mean C:N ratio in upper soil layer was highest under mixed crops field (11.36: 1.2) and lowest under primary forest (9.39: 0.6). When soil OC and TN were converted into stocks primary forest 10 year old teak, cocoa plantation and mixed crops field stored 15.36: 3.03; 16.11: 4.8; 13.72:2.80; 11.20:4.77; 11.16 : 4.97 t ha^{-1} OC respectively, mixed tree plantation had higher OC the other land uses types.

Srinivasan *et al.* (2010) opined that tree-based land use system has the potential to improve soil fertility. Incorporation of trees improved the soil organic matter status compared to sole coconut plots. Leguminous trees are effective in improving soil fertility. Tree based land use system has the potential to improve soil fertility. Incorporation of trees improved the available N, P, K content of the soil as compared to sole coconut plots. Leguminous trees are effective in improving soil fertility.

Eludoyin and Wokocha (2011) evaluated the impacts of maize cultivation on soil properties under the continuous monocropping system of farming in South–western Nigeria. The result shows that the level of C, N and porosity were higher in soils under forest than soils under maize. However, there was no significant difference in Exchangeable Acidity, Mg, Soil pH and Ca in the two land use types. Nevertheless, the concentrations of Na and K were higher in the cultivated soils while P and Ca were lower in the cultivated soils. The particle size composition was predominantly sandy. Planting of cover crops, mixed cropping and mulching among others were suggested as ways to minimize erosion and leaching so that fertility can be restored and maintained.

Kumar *et al.* (2011) studied the effect of castor based intercropping system on yield and post-harvest nutrient status of soil and observed that available nitrogen, phosphorous and potassium content of soil were higher (299, 38 and 309 kg ha^{-1}, respectively) when castor intercropped with groundnut in 1:3 row proportion as compared to sole cropping (280, 33 and 298 kg ha^{-1}, respectively).

Kumari *et al.* (2011) opined that the active fraction of soil organic carbon (SOC) was significantly higher in a plot receiving 100% NP over the one receiving only 100% N or control. Continuous application of organic manure alone or in combination with inorganic fertilizer enriched the soil with total organic carbon (10.9 g kg^{-1}), humic fractions (2.43 g kg^{-1}) and raised optical density of humic acid (4.40) and fulvic acid (7.70). However, sole application of fertilizers caused gradual deterioration in soil fertility with lower organic carbon content. Integrated use of FYM with chemical fertilizers or use of FYM alone exerted significant effect on the active and passive pools of soil carbon.

Pellegrino *et al.* (2011) reported that after 10 years of different land uses including short rotation coppice poplar stand, intensive agriculture and uncultivated systems there were no significant impacts of management on soil CEC and EC. However, soil pH was significantly affected by different treatments and was significantly higher in 3 year cutting cycle of poplar.

The soil organic carbon increased by 107% under *shisham* followed by *kikar* (92.4%) over control (3.30 g kg^{-1}) in the surface soil layer. The N content was higher under *subabul* (87.9 mg kg^{-1} in surface layer); whereas P and K were higher under *kikar* (9.5 and 142 mg kg^{-1}, respectively in surface layer) than other tree species. Available micronutrients were higher beneath *subabul and kikar* than *shisham* and *khair* in the surface layer as well as whole soil profile (Baljit Singh and Sharma, 2012).

Math and Halikatti (2012) observed that, the available N, P and K status was improved by growing soybean and french bean in 1:2 row ratio with maize (221.33 and 245.43 kg/ha, 36.42 and 35.32 kg/ha and 366.45 and 369.62 kg/ha, respectively) as compared to sole maize (221.33, 32.28 and 361.58 kg/ha, respectively).

Swain *et al.* (2012a) reported that among various intercropping systems, mango + guava + cowpea and mango + guava + french bean systems resulted in increases in soil pH to 6.74 and 6.70 at 0–15 cm deep and 6.70 and 6.68 at 15–30 cm deep as compared to the soil pH of 6.30 and 6.25 under no intercropping. The electrical conductivity of orchard soil as observed in the study under mango + guava + cowpea and mango + guava + french bean systems was increased to 84.5 µmhos cm^{-1} and 83.4 µmhos cm^{-1} at 0–15 cm deep and 67.6 µmhos cm^{-1} and 65.6 µmhos cm^{-1} at 15–30 cm deep, respectively. The maximum improvements in the organic C contents in depths of 0–15 cm and 15–30 cm were 0.70% and 0.63%, respectively, under mango + guava + cowpea intercropping system, which was comparable with the results of the mango + guava + french bean system.

The maximum soil fertility improvement was recorded in mango+cowpea-toria agri–horticulture model (AHM) followed by mango+black gram-toria and mango+pigeon pea AHM, whereas minimum with mango+sesame-toria AHM. The improvement in organic carbon (11.63-49.05%), total nitrogen (6.25-56.25%), phosphorus (10.27-48.63%), potash (20.7-58.46%) and reduction in pH (12.12-15.62%) was recorded in fruit based agri–horticultural model compared with the initial value recorded in 1995 before the establishment of orchard. Sole plantation without inter-crops also showed significant

increase in organic carbon (9.80%), total nitrogen (5.0%), phosphorus (11.23%), potash (13.08%) and reduction in pH (7.6%) (Avinash Chandra Rathore *et al.,* 2013).

Chintala *et al.* (2013) studied the effect of biochar addition on the chemical properties of acidic soil such as soil pH, electrical conductivity (EC), cation exchange capacity (CEC), and exchangeable acidity. Amendment type, application rate, and their interaction had significant effects on soil pH, EC, and CEC of acidic soil. Exchangeable acidity was significantly affected by amendment type. Application of corn stover biochar had shown a relatively larger increase in soil pH than switchgrass biochar at all application rates. The ameliorating effect of biochar on chemical properties of acidic soil was consistent with their chemical composition.

The organic carbon content of the soil has increased significantly in all the treatments that received NPK at different levels. The highest value of 6.2 g kg^{-1} was recorded in the treatment receiving NPK+FYM @ 10 t ha^{-1} which 55 per cent higher than control. The status of Ca and Mg in soil had increased significantly in all treatments recording the highest status on continuous application of integrated fertilizer management. The micronutrients like iron, zinc, manganese and copper were significantly higher in the treatment receiving 100 per cent NPK + FYM (Hemalatha and Chellamuthu, 2013).

The physico-chemical properties of soil in *Vigna mungo* and *Triticum aestivum* grown in agroforestry system at 0–15, 15–30 and 30–60 cm depths of soil revealed that soil pH increased whereas electric conductivity and bulk density decreased from top to bottom. pH increased from 7.77 to 8.02 and 7.60 to 7.87, electric conductivity decreased from 0.22 to 0.15 and 1.18 to 1.06 in *Vigna mungo* and *Triticum aestivum*, respectively. Bulk density increased from top to bottom and it was 1.07 to 1.13 and 0.51 to 0.61 in *Vigna mungo* and *Triticum aestivum*, respectively. Organic carbon and potassium showed a depth wise decrease from 0.73 to 0.51 and 0.60 to 0.47 and potassium from 51.65 to 39.84 and 91.18 to 54.02 in *Vigna mungo* and *Triticum aestivum*, respectively (Rupinder Kaur and Sunil Puri, 2013).

Sharma *et al.* (2013) reported that soils under forest ecosystem showed lower pH as compared to rice ecosystem and high OM content under forest ecosystem might be the cause for the lower pH values, whereas higher pH values under rice ecosystem might be due to continuous cultivation of rice in the same field for long period. EC values remained almost same under both tree-based and rice-based cropping system. Slightly higher CEC values were observed under rice land use pattern than under tree plantations. Possible explanation of this is the higher clay content and higher OM accumulation in rice land use system.

Pranav Kumar *et al*. (2014) studied the effect of different potassium levels on mungbean under custard apple based agri–horti system. Potassium application is directly related to growth, plant biomass and yield in crops. Results showed that application of different potassium levels gave varying yield. Lowest yield (700 kg ha^{-1}) was obtained with the application of '0' kg ha^{-1} and highest yield (1096 kg ha^{-1}) was obtained with the application of 120 kg ha^{-1} potassium. It is concluded that the application of 80 kg ha^{-1} potassium gave highest benefit: cost ratio of mungbean and looks more remunerative.

Sarvade *et al.* (2014) reported that the organic carbon was highest under poplar (1.73%) as compared to control (open farming system) (0.60%). The electrical conductivity was significantly lowered under *leucaena* interfaces as compared to control. Whereas, soil pH was lower under poplar (at 3.0×2.0 m^2) and statistically similar with *leucaena* (at 3.0×1.0 m^2). Bulk density was significantly decreased under *leucaena* and melia interfaces at 3.0×1.0 m^2 spacing. Highest available N, P_2O_5 and K_2O content (200.42, 18.67 and 169.12 kg ha^{-1}, respectively) were observed in the soil under *leucaena* (3.0×2.0 m^2).

Nancy Loria *et al.* (2016) conducted an experiment with different cropping systems and reported that the order of available nitrogen as affected by cropping systems in soil surface was vegetable (267.21 kg ha^{-1}) > agroforestry (227.74 kg ha^{-1}) > cereal (223.22 kg ha^{-1}) > fruit (185.11 kg ha^{-1}) > control (157.36 kg ha^{-1}). Available phosphorus followed the order; vegetable (19.99 kg ha^{-1}) > agroforestry (18.93 kg ha^{-1}) > cereal (17.55 kg ha^{-1}) > fruit (15.03 kg ha^{-1}) > control (9.84 kg ha^{-1}). The order of available

potassium in surface soils was; vegetable (172.42 kg ha^{-1}) > agroforestry (168.87 kg ha^{-1}) > cereal (168.07 kg ha^{-1}) > fruit (146.57 kg ha^{-1}) > control (119.46 kg ha^{-1}). The soil bulk density was in the order: control (1.34 Mg m^{-3}) > fruit (1.32 Mg m^{-3}) > agroforestry (1.28 Mg m^{-3}) > cereal (1.22 Mg m^{-3}) > vegetable (1.19 Mg m^{-3}).

Swain (2016) indicated that the maximum improvement in the organic carbon content in 0–15 cm and 15–30 cm soil depths was recorded to be as 0.72% and 0.65%, respectively under guava + cowpea intercropping system, which was comparable with the results of the guava + french bean system. among different intercropping systems tried, the guava + cowpea and guava + french bean systems significantly increased the maximum available nitrogen content of soil to 353.2 and 338.3 kg ha^{-1} within 0–15 cm and 313.8 and 301.9 kg ha^{-1} within 15–30 cm soil depths, respectively. The available phosphorus content of soil under guava + mango ginger, guava + turmeric and guava + cowpea systems were increased to 20.9, 20.6 and 20.4 kg ha^{-1} within 0–15 cm and 18.9, 18.0 and 18.3 kg ha^{-1} within 15-30 cm soil depth, respectively. The guava + cowpea intercropping system proved advantageous in increasing the available potassium contents of soil to 371.4 and 336 kg ha^{-1} within 0–15 cm and 15–30 cm soil depths, respectively.

An experiment conducted in Pear orchard of Kashmir, India at different altitudes revealed that the pH in the surface layer (0–25 cm) in high, mid and low altitudes was 6.10, 7.76 and 6.75, respectively and the soil EC was 0.10 to 0.44 and 0.26 dS m^{-1} in high, mid and low altitudes, respectively. The organic carbon content was 0.66, 2.36 and 1.54 per cent, in high, mid and low altitudes, respectively. The available nitrogen (401.5, 345.7 and 312.4 kg ha^{-1}), phosphorus (30.7, 29.7 and 24.1 kg ha^{-1}) and potassium (352.64, 288.43 and 235.84 kg ha^{-1}) were found in high, mid and low altitudes, respectively (Dar *et al.,* 2017).

Kaushik Usha *et al.* (2017) conducted an experiment to know the effect of cultivation of citrus on soil organic carbon and nutrient status. The results showed that the organic carbon content was 14.50% higher under cultivated soil as compared to path soil. This may be due to higher addition of organic matter in the orchard through continuous litter fall. The pH and EC of the orchard soil was reported lower as compared

to the path soil. The available nitrogen was found 11% higher in soil of citrus orchard. Similarly, the content of available phosphorus, sulphur, zinc, manganese and copper was found 74.4%, 62.80%, 123%, 40% and 48% respectively higher than the controlled samples.

Soils of different horticultural land use systems were alkaline in reaction, soils under pomegranate land use system recorded lowest mean value of pH (7.92) and soils under coconut land use systems recorded higher mean value of pH (8.38) compared to soils under other land use systems. The salt content present in soils varied from 0.19 to 0.88 dS m^{-1} under different land use system indicating normal to critical in range for growing of different crops. Soils under coconut land use system recorded lowest electrical conductivity (dS m^{-1}) (0.19) and highest in areca nut land use system (0.88) compared to soils under other land use systems. Higher available nitrogen (365.28 kg ha^{-1}) was observed under coconut land use system and lowest available nitrogen under onion land use system (245.57 kg ha^{-1}) compared to other land use systems. Among the different land use systems, highest available phosphorus (32.66 kg ha^{-1}) was observed under coconut land use system and lowest available phosphorus (24.24 kg ha^{-1}) observed under chilli land use system. Available potassium was highest under coconut land use system (325.20 kg ha^{-1}) and lowest under areca nut land use system (266.82 kg ha^{-1}) among all the land use systems (Purnananda *et al.,* 2017).

Rajwinder Kaur and Bhat (2017) concluded that soils from cropland as well as forest land use systems at Takarla and forest as well as grassland systems at Mukerian contained more clay and silt. Available N, P and K at Takarla and Mukerian varied from 37.78 to 234.78 and 40.48 to 264.47, 3.81 to 21.44 and 3.19 to 18.56, 15.83 to 286.67 and 6.66 to 149.17 kg ha^{-1}, respectively. Available N was significantly higher in forest whereas, available P and K were significantly higher in cropland compared with agro–forestry and grassland. The highest (5.00 g kg^{-1}) concentration of soil organic carbon was in the forestry at Takarla and at Mukerian, grassland possessed higher (15.88 g kg^{-1}) value followed by forestry.

The soil available N ranged from 182 kg ha^{-1} under fodder maize to 257 kg ha^{-1} under custard apple + cowpea in 2012; 184 kg ha^{-1} under fodder maize to 261 kg ha^{-1} under custard apple + cowpea in 2013 with a mean soil N of 218 and 222 kg ha^{-1} in the two years, respectively. The soil available P_2O_5 ranged from 39.7 kg ha^{-1} under fodder maize to 64.6 kg ha^{-1} under custard apple + cowpea in 2012; 40.8 kg ha^{-1} under fodder maize to 71.1 kg ha^{-1} under custard apple + cowpea in 2013 with mean of 56.3 and 59.5 kg ha^{-1} in the two years, respectively. The soil available K_2O ranged from 77 kg ha^{-1} under fodder maize to 140 kg ha^{-1} under custard apple + cowpea in 2012; 79 kg ha^{-1} under fodder maize to 143 kg ha^{-1} under custard apple + cowpea in 2013 with mean of 107 and 109 kg ha^{-1} in the two years, respectively (Ramulu *et al.,* 2017).

Ravindra Kumar *et al.* (2017) collected soil samples from four different locations of Meerut and Bulandshare districts (U.P) under rice - wheat cropping system and analysed for different soil properties. Their results showed that pH ranged from 7.4 to 8.9, EC from 0.169 to 0.500 dS m^{-1}, the CEC from 13.30 to 22.20 cmol (p^+) kg^{-1}, organic carbon from 6.2 to 6.9%. Available nutrients (kg ha^{-1}) are ranged as: N–99.65 to 134.05, P_2O_5–2.65 to 17.52 and K_2O–90.71 to 317.51. Micronutrients (ppm): Cu–0.825 to 1.349, Fe–6.783 to16.923, Zn–0.423 to 1.621 and Mn–2.667 to 5.091.

The electrical conductivity of orchard soil was increased under guava + banana systems throughout the soil layer (0–45 cm) as compared to control plot *i.e.,* guava + no intercrop. The guava + banana and guava + eggplant system were most effective with increase in soil pH as compared to control plots *i.e.,* guava + no intercrop (Saswati Ghosh *et al.,* 2017).

Subba and Dhara (2017) studied different fruit based agroforestry systems and found that there was a significant variation in soil chemical properties. At soil depth 0–15 cm, revealed that soil pH vary from 5.81 to 5.90 in case of *Alnus nepalensis* + *Citrus reticulata* + intercrops and in *Alnus nepalensis* + *Pyrus communis* + intercrops ranges from 5.78 to 5.87. The less change in pH was noticed in both sole fruit trees plantation (5.78 and 5.75). The highest (2.04%) of organic carbon was found at 0–15 cm depth in *Alnus nepalensis* + *Citrus reticulata* + pea + mustard followed by *Alnus nepalensis* +

Pyrus communis + pea + mustard (1.93%). It was (1.69%) in sole *Citrus reticulata*. It also revealed that lowest (1.63%) organic carbon was recorded in sole *Pyrus communis* fruit tree. The available N at the end of experimentation in fruit based agroforestry system revealed that the highest available nitrogen (517.00 kg ha^{-1}) was observed in *Alnus nepalensis* + *Citrus reticulata* + pea + mustard followed by *Alnus nepalensis* + *Pyrus communis*+ pea + mustard (514.00 kg ha^{-1}) at 0-15 cm depth. The lowest nitrogen content was recorded in sole fruit trees (456.00 and 449.00 kg ha^{-1}) in *Citrus reticulata* and *Pyrus communis*, respectively. The available phosphorous was found highest in *Alnus nepalensis* + *Citrus reticulata* + pea + mustard (14.38 kg ha^{-1}) followed by *Alnus nepalensis* + *Pyrus communis* + pea + mustard (14.26 kg ha^{-1}). The lowest phosphorous content was found in sole fruit trees (13.51 and 13.37 kg ha^{-1}) in *Citrus reticulata* and *Pyrus communis* plot respectively. *Alnus nepalensis* + *Citrus reticulata* + pea + mustard showed highest available potassium content (535.00 kg ha^{-1}) followed by *Alnus nepalensis* + *Citrus reticulata* + french bean + cauliflower (524.00 kg ha^{-1}). Lowest soil potassium content was observed in sole *Citrus reticulata* and *Pyrus communis* (476.00 and 469.00 kg ha^{-1}) plots.

Anand Salve *et al.* (2018) revealed that chemical parameters were found decreasing with increasing of soil depth. Organic carbon was significantly higher in agri–horti-silviculture system (1.26%) and at 0–15 cm depth in high hills temperate dry and cold climatic condition (1.26%). Similarly exchangeable Ca (5.52 mg/100g) was significantly higher in agri–horti-silviculture system and at 0–15 cm depth (6.03 mg/100g). Most of the soil samples were of alkaline property. Maximum soil pH (8.21) was recorded in high hills temperate dry and cold climatic condition which was significantly differ with dry temperate high hills climatic condition. Deep soil layer (15–30 cm) showed maximum pH, N (0.25%), P (0.97 mg/100g) and K (1.69 mg/100g) was significantly higher at upper (0–15 cm) layer of soil.

Khanday *et al.* (2018) analysed the nutrient content of horticulture growing soils (Gotlibag, Wangth and Kullan) of Ganderbal District. According to them the average nutrient content of surface soils of these areas are: available N, P_2O_5 and K_2O (364.10, 16.55 and 343.74 kg ha^{-1}), micronutrients (ppm) Fe (32.42), Zn (1.46), Mn (26.02) and

Cu (1.51). Soil fertility exhibits the status of different soils with regard to the amount and availability of nutrients essential for plant growth.

The highest pH value was recorded in crop fields without tree/shrub species (OC) system (7.9) while the other systems were sustained to the standard pH (6.8–7.2). The application of more chemical pesticides and fertilizers in crop fields might have increased the pH considerably. Soil carbon was better recorded in the surface layer compared to deeper layer and decreased from 1.60% (crop fields with multiple tree species, C + mT) to 0.93% (OC). The total organic content ranged from 1.22% (OC) to 2.08% (C + mT) and soil carbon and nitrogen contents followed the same pattern. The soil phosphorus ranged from 26.34 (ADL) to 48.73 kg/ha (C + mT) (Kirtika Padalia *et al.,* 2018).

Lyngdoh and Karmakar (2018) studied the three soil profiles, from Ri-Bhoi district B1, B2 and B3 and soil samples were collected from areas under agricultural crop, tea, and forest and analysed for different physic-chemical properties. The soil texture varied from sandy to clayey. The soils varied widely in OC (0.39–1.20 per cent), bulk density (0.97–1.67 gm/cc), pH (4.5–5.4), base saturation (18.1–50.9 per cent) and available N (501.8–715.0 kg ha^{-1}), P_2O_5 (9.8–32.1 kg ha^{-1}), K_2O (241.9–392.3 kg ha^{-1}).

Meena *et al.* (2017) showed that the increase in Olsen–P in plots receiving FYM applied either alone or in combination with NPK 33.22 % and 52.26 % than control was due to release of organically bound P during decomposition of organic matter, solubilization of soil P by organic acids produced during decomposition of organic matter. Continuous application of FYM also reduced the activity of polyvalent cations such as Ca, Fe, and Al due to chelation which, in turn, considered responsible for reduction in P–fixation

Within the forestry fragment, the 0.00–0.10 m layer showed the highest organic carbon (OC) content in the higher aggregate classes 4–2 and 2–1. At the same depth, the class of 0.5–0.25 mm presented the highest OC content compared to the class of aggregates 1–0.5 mm. In the agroforestry system, the mean OC contents ranged from

4.94 to 7.12 g kg^{-1}, with no differences between the classes of aggregates (Rocha Junior *et al.,* 2018).

2.2.3 Biological properties

A field study was conducted to determine the activity and persistence of soil enzymes with repeated additions of different organic residues. The enzyme activity assayed in the amended soil was increased by an average of 2–4 fold by incorporation of the four organic amendments when compared with the unamended soil (tillage alone) during the 31–month study. In general, the addition of organic amendments greatly increased the enzyme activity during the first year of the experiment, but subsequent additions failed to sustain high enzyme activity in the amended soil. The straw amendment was the most effective amendment enhancing the soil enzyme activity for all the enzymes assayed except for urease (Martens *et al.,* 1992).

Chander *et al.* (1997) showed that inclusion of a green manure crop of *Sesbania aculeata* in the rotation improved soil organic matter status and led to an increase in soil microbial biomass, soil enzyme activity and soil respiratory activity. Microbial biomass C increased from 192 mg kg^{-1} soil in a pearl millet-wheat-fallow rotation to 256 mg kg^{-1} soil in a pearl millet-wheat-green manure rotation. Inclusion of an oilseed crop such as sunflower or mustard led to a decrease in soil microbial biomass, C mineralization and soil enzyme activity. There was a good correlation between microbial biomass C, ninhydrin–N and dehydrogenase activity. The alkaline phosphatase activity of the soil under different crop rotations was little affected.

Singaram and Kamala Kumari (2000) reported that the level of activity of soil enzymes (amylase, catalase, cellulase, dehydrogenase [oxidoreductase], phosphatase [phosphoric monoester hydrolases] and urease) as influenced by continuous application of fertilizers and farmyard manure (FYM) was monitored during 1972–92. The study was carried out on *Typic Ustropept* clay loam soils in Coimbatore, Tamil Nadu, India. Results indicated that FYM addition stimulates soil enzyme activity. Enhanced activity of soil enzymes upon the addition of graded doses of NPK implies that continuous addition of inorganic fertilizers for 20 years has no marked detrimental effect on the enzyme

dynamics of the soil. The enhanced levels of soil enzyme activity due to the addition of FYM promoted the recycling of nutrients in the soil. In another study it was found that agroforestry species enhanced the activity of acid phosphatase, while maize enhanced the activity of alkaline phosphatase. Acid phosphatase activity increased exponentially with increasing proximity to the root mat of the agroforestry species. This suggests that agroforestry species are actively increasing rhizosphere phosphatase activity either directly by secretion or indirectly by stimulation of microbial activity (George *et al.,* 2002).

The soil microbial biomass was significantly affected by the tree-crop combination. Both the amounts of microbial biomass C as well as dehydrogenase and alkaline phosphatase activities were greater in soils under *D. sissoo*. The microbial biomass C was maximum in the narrowest tree spacings and decreased with increase in spacing. In soil where only crops were grown, the microbial biomass and enzyme activities were the lowest. Adoption of a tree-crop combination could lead to increased long-term sustainability of soil fertility by improving levels of soil organic matter, available nutrients and soil microbial activity (Chander *et al.,* 1998). Urease activity is directly related to amount of organic matter present in soil (Renato Roscoe *et al.,* 2000). Enzyme activities of soils are usually correlated with their organic carbon and available N contents (Taylor *et al.,* 2002).

Tithonia (29.64 nmol MUB min^{-1} g^{-1} soil) and *Crotalaria* (36.08 nmol MUB min^{-1} g^{-1} soil) had greater phosphatase activity at 0–1 mm from their root than did maize (15.75 nmol MUB min^{-1} g^{-1} soil). Agroforestry species enhanced the activity of acid phosphatase, while maize enhanced the activity of alkaline phosphatase. Acid phosphatase activity increased exponentially with increasing proximity to the root mat of the agroforestry species. This suggests that agroforestry species are actively increasing rhizosphere phosphatase activity either directly by secretion or indirectly by stimulation of microbial activity and/or depletion of Pi. Overall, agroforestry species enhanced phosphatase activity in their rhizosphere (George *et al.,* 2002). The microbial biomass and activity are the main biological indicators of soil quality and respond rapidly to changes resulting from agronomic practices (Araujo *et al.*, 2003). Kumar and Goh (2003)

reported that higher dehydrogenase activity under legume crops may be due to the fact that leguminous crops which low C:N ratio, especially contain easily available compounds, such as amino acids and carbohydrates, which can stimulate the microbial population and increase the dehydrogenase activity.

Balota *et al.* (2004) investigated soil enzyme activities in a split-plot experiment (3 replications) where tillage (no till and conventional) was the main plot and crop rotation (soybean/wheat, S/W; maize/wheat, M/ W or cotton/wheat, C/W) was the subplot. The 0–5 cm layer under NT system showed increases up 68% for amylase, 90% for cellulase, 219% for arylsulfatase, 46% for acid phosphatase, and 61% for alkaline phosphatase. There were significant correlations of soil enzyme activities with total organic C, and C and N microbial biomass. These results showed that NT increased microbial activity and that soil enzyme activity is a sensitive indicator of alteration soil quality by management.

Dinesh *et al.* (2004) reported that incorporation of leguminous cover crops significantly enhanced organic C by 1.9–4.6 g kg^{-1} and total N by 0.52–0.78 g kg^{-1} after the 10-year period. The Bray P and K levels were also increased by 1.3–2.3 and 3.2–4.2 mg 100 g^{-1}, respectively. Consequently, all the biochemical variables related to microbial activity (biomass C and N, N flush, CO_2 evolution, qCO_2, ATP, N mineralization and activities of dehydrogenase and catalase) were at significantly greater levels, thereby reflecting the response of greater organic matter inputs to the soil.

Soil acid phosphatase activity in the rhizosphere of chickpea was significantly higher than maize regardless of P sources. Chickpea can mobilize organic P in soil, leading to an interspecific facilitation in utilization of organic P in maize/chickpea intercropping (Li *et al.,* 2004).

Soil urease is produced by soil microbes which play a vital role in nitrogen cycle by hydrolysis of urea into ammonia, carbon dioxide and water which are beneficial for plants absorption (Zhang *et al.,* 2004). In a field experiment, all soils, including bulk soil showed acid phosphatase activity. Phosphatase activity was about 1.5 times higher in

rhizosphere soil of maize, *C. spectabilis* and C. *Serrata* than in bulk soil. Phosphatase activity was over 2 times higher in rhizosphere soil of *E. grandis* than in bulk soil and phosphatase activity was 5 times higher in rhizosphere soil of *G. robusta* than in bulk soil. The differences between these three levels were highly significant. There were no significant differences in phosphatase activity of rhizosphere soil between +P and −P treatments within one species (Simone and Pauline, 2004).

Manna *et al.* (2005) reported that dehydrogenase activity in soils increased significantly with application of NPK + FYM as compared to NPK alone.

Rajendra Prasad and Mertia (2005) studied the dehydrogenase activity and VAM fungi association in rhizosphere of five agroforestry trees (*Azadirachta indica*, *Acacia tortilis*, *Eucalyptus camaldulensis*, *Prosopis cineraria* and *Tecomella undulat*a) under irrigated and rainfed conditions in the arid zone of India. Higher dehydrogenase activity (9.5 to 16.8 p kat g soil^{-1}), root colonization (58.3 to 68.5%) and spore density (132.5 to 234.7 spores 100 g soil^{-1}) were observed in tree rhizosphere as compared to that in non–rhizosphere (7.4, 37.7 and 44.4). Irrigation had increased dehydrogenase activity by 22.1% while it reduced root colonization and spore density by 14.2% and 16.2%, respectively.

Hu *et al.* (2006) conducted an experiment to understand how soil fertility maintaining practices, such as chemical fertilizer application, the use of organic manure and the return of crop straw to the field affected soil microbial biomass carbon (MBC) dynamics in a low production agro-ecosystem of northern China. The experimental results showed that: manure application enhanced the content of MBC throughout the experimental stage; a single chemical fertilizer application could elevate the content of MBC, but chemical fertilizer cooperating organic material could more increase the content of MBC; and that different compositions of straw (wheat straw + corn straw, double wheat straw and wheat straw) returned to the field produced distinct variations in different seasons. Organic manure showed an obvious increase in the content of MBC. The content of MBC had the following ascending trend with regard to annual average the content of MBC: Wheat Straw + Corn Straw + Chemical Fertilizer + Organic Fertilizer >

Wheat Straw + Chemical Fertilizer + Organic Manure > Wheat Straw + Corn Straw + Chemical Fertilizer > Double Wheat Straw + Chemical Fertilizer > Wheat Straw + Chemical Fertilizer > Chemical Fertilizer > Control. Therefore, manure applications heighten soil microbial activity and improve soil fertility.

Singh and Yadava (2006) in their study reported that soil microbial biomass C, N and P were recorded to be higher in upper layer (0-10 cm depth) of the soil and contributed 72%, 67%, 68% and 73%, 66%, 68% of microbial biomass to total annual microbial biomass in grassland and agroecosystem respectively. The soil microbial biomass decreases with the increase of soil depth in both the ecosystems.

The microbial biomass C and N were low in the control treatment and the fertilizer N treatment and increased significantly with application of manure, fertilizer NPK or rice straw + fertilizer N. The manure + straw + N treatment had a maximum microbial biomass N followed by PK + N and manure + PK + N treatment. The microbial biomass N ranged from 51 to 70 mg kg^{-1} and accounted for 3.1 to 4.0 per cent of the soil total N. Manure application alone had maximum microbial biomass C. The microbial biomass C ranged from 505 to 676 mg kg^{-1} and accounted for 2.9 to 3.3 per cent of the soil organic C (Dezhi Yan *et al.,* 2007).

Haiyan Chu *et al.* (2007) revealed that long-term fertilization greatly increased soil microbial biomass C and dehydrogenase activity, except that the P-deficiency fertilization had no significant effect. Organic manure had a significantly greater impact on the biomass C and the activity, compared with mineral fertilizers. Microbial metabolic activity (dehydrogenase activity per microbial biomass C) was significantly higher under balanced fertilization than under nutrient-deficiency fertilization.

Madejon *et al.* (2007) reported that the dehydrogenase, an oxido-reductase that only exists in viable cells and is considered a sensitive indicator of soil quality and was strongly correlated with soil organic carbon content.

The microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) values in NPK + lime and NPK + FYM treatments were statistically not significant. The

MBC ranged from 3.8 per cent to 5.8 per cent of SOC and MBN from 1.5 to 2.7 per cent of total N in the surface layer (0 to 15 cm) whereas in lower depths the MBC/SOC ratios were relatively higher in all treatments (Manna *et al*., 2007). Kadlag *et al.* (2008) reported higher activity of phosphatase enzyme under intercropping systems which might be due to higher added organic matter along with inorganic fertilizer which intern increased the organic carbon and nitrogen.

Mishra *et al.* (2008) studied that the CO_2 evolution, MBC, MBN, MBP, MBS, water soluble carbon, carbohydrate, urease and phosphatase were significantly higher in treatment receiving 100% NP over treatment receiving only 100% N or control. The 100% NPK treatment did not show significant changes in microbial and enzymatic activity over 100% NP treatment. The pH, organic carbon, CO_2 evolution, MBC, MBN, MBP, MBS, water soluble carbon, carbohydrate, urease and phosphatase enzyme were found highly significantly correlated with grain yield and nutrient uptake (NPK).

Ranjith *et al.* (2008) reported that the dehydrogenase activity was higher in grassed areas compared with crop treatments. Grass buffers and grass waterways exhibited an average production of 79.1±7.5 and 65.5±7.2 mg TPF g^{-1} dry soil h^{-1}, respectively. The lower levels of dehydrogenase activity within cropped areas differed slightly between agroforestry buffer and row crop treatments, which contained an average TPF production of 51.0±7.5 and 48.0±5.2 mg TPF g^{-1} dry soil h^{-1}, respectively.

Supradip Saha *et al.* (2008) reported that only inorganic fertilized treatments and control showed significantly lower intracellular metabolism of soil microbes, which depicts dehydrogenase activity. NP, NK and NPK showed similar levels of activity, on par with the control. Improvement in soil dehydrogenase activity was more than five times in NPK + FYM over control treatment. Rai and Yadav (2011) reported maximum activity of dehydrogenase activity in the rhizosphere of legumes crops compared to other.

Tejada *et al.* (2008) reported that all green manures had a positive effect on the soil biological properties, plant nutrition an crop yield parameters, although at the end of the experimental period and at the high organic matter rate, the soil microbial biomass

and dehydrogenase, urease, beta-glucosidase, phosphatase and arylsulfatase activities increased more significantly in the residues of *Trifolium pratense* (TP) amended soils (79.2%, 92.1%, 93.9%, 99.3%, 87.9% and 96%, respectively) respect to the control soil, followed by residues of *Trifolium pratense* (TP)+ *Brassica napus*, L. (BN) amended soils (77.3%, 90.9%, 92.8%, 99.1%, 84.4% and 95.7%, respectively) and BN amended soils (76%, 90.1%, 91.7%, 99%, 83.2% and 95.2%, respectively). Since these soil enzymatic activities measured are responsible for important cycles such as C, N, P and S, an increase of leaf N, P an K contents and pigments and soluble carbohydrate contents were highest in TP amended soils, followed by TP+BN and BN treatments.

Ranjith Udawatta *et al.* (2009) showed that the grassed areas exhibited significantly greater dehydrogenase activity compared with tree + grass vegetation treatments. Grass buffers and grassed waterways produced an average of 79 and 65 mg TPF g^{-1} dry soil h^{-1}, respectively. The lowest level of dehydrogenase activity within the cropped area was slightly lower than the agroforestry (AG) treatment. The AG and crop (CS) treatments showed similar rates of TPF production of 51 and 48 mg TPF g^{-1} dry soil h^{-1}, respectively.

Verma and Mathur (2009) studied the effect of integrated nutrient management on active pools of soil organic matter under maize-wheat cropping sequence of a *Typic Haplustept*. Application of FYM @ 20 t ha^{-1} significantly increased the microbial biomass carbon, water soluble carbon and water soluble carbohydrates, whereas maximum amount of soil microbial biomass nitrogen and dehydrogenase activity was found in 100; NPK + 10 t FYM ha^{-1} treatment and maximum soil microbial biomass phosphorus was observed in 150; NPK treatment compared to sole use of chemical fertilizers. Integrated use of FYM with chemical fertilizers or use of FYM alone exerted significant effect on the active pools of soil carbon.

He *et al.* (2010) measured the activities of acid phosphatase, alkaline phosphatase, phosphoro-diesterase and non-buffered and buffered urease in soils under rainfed and irrigated potato with different crop rotation managements. Compared with continuous potato (*Solanum tuberosum* L.) production, three-year rotation practices increased all soil

enzyme activities in rainfed condition by 10 to 86%. Under rainfed management, microbial biomass C level was highly correlated with phosphatase and urease activities. When measured under buffered conditions, urease activity was highly correlated with rainfed potato yield. To the extent that urease is an indicator of plant N availability, this may reflect the influence of N availability on yield. This study showed that both cropping system and water management influence the activities of several enzymes considered important for plant uptake of N and P.

Lopes *et al.* (2010) opined that soil microbial C values were higher in native forest and *P. maximum* when compared to the other plots. The soil basal respiration values were similar among all plots evaluated. However, respiratory quotients were significantly lower in native forest and *P. maximum* when compared to other plots, at 0–10 cm depth. Soil microbial biomass and activity changed when a native forest was converted to pastures. These changes were positive with the inclusion of *P. maximum* by the high input of C sources.

Upendra and Andrew (2011) observed that forages grown in rotation with or without durum influenced above– and below–ground biomass C inputs and soil C fractions. SOC (18.7 Mg C ha^{-1}) and particulate total carbon (4.8 Mg C ha^{-1}) at the 0–15 cm depth and potential C mineralization (351.0 kg C ha^{-1}) and microbial biomass C (816 kg C ha^{-1}) at 0-120 cm were greater under alfalfa than under durum-annual forage sequences. Continuous cropping can also increase the amount of crop residue returned to the soil and organic matter compared with crop-fallow (Sainju *et al*., 2009).

Mao *et al.* (2012) found that although land use change from monocropping to poplar based agroforestry system increased soil MBC both in the 0–15 cm and 15–30 cm layers irrespective of soil texture, but soil MBN increased only in the 15–30 cm layer which was probably attributed to the high amount of N fertilizer application (120–150 kg N ha^{-1} yr^{-1}) or shift in soil microbial community structure.

Similar studies were conducted by Pramod *et al.* (2012) on dehydrogenase activity (DHA) under forest, horticulture and agriculture land use in Central India and

observed that the DHA activity under different land use systems ranged from 18 to 647 µg TPF g^{-1}. It was highest under the forest land use (647 µg TPF g^{-1} soil) followed by horticulture (97.1 µg TPF g^{-1} soil) and cropland had the least value. Higher DHA under forest land use is an indication of the strong catabolic activity of soil microorganisms. On the other hand, within the agricultural land use, highest DHA was recorded in plots fertilized with organic manure (78.1 µg TPF g^{-1} soil) and lower activity was observed under recommended dose of fertilizer (47.7 µg TPF g^{-1} soil). This suggests that dehydrogenase activity is adversely affected by chemical fertilizer application.

Ullah *et al.* (2012) investigated the impact of different seasonal variations and cropping systems on soil microbial biomass and enzymatic activities in sloppy arid soils. The results revealed that the soil microbial biomass carbon (C_{mic}), nitrogen (N_{mic}), phosphorous (P_{mic}), soil enzymes such as dehydrogenase (DH) and alkaline phosphatase (AP) activity entirely depends on the soil water availability under both cropping systems at all height terraces. The wheat-mung bean cropping systems stored relatively more N_{mic}, P_{mic}, AP (activity) and less C_{mic}, DH (activity) as compared to wheat–millet cropping systems. Pertaining to seasonal variations under both cropping patterns, the summer season had shown more C_{mic}, N_{mic}, P_{mic}, DH and AP activity as compared to spring, winter and autumn season in all types of terraces. In conclusion, it is suggested that in arid environments, cover crops be included in cropping system in order to enhance soil biological health.

Significant differences were observed in microbial biomass N (N_{mic}) in upper layer. Microbial biomass N was significantly higher in G_2 (intercropped with grafted ginkgo seedlings at a spacing of 6 m × 8 m) than in other two systems both in middle and lower layers and there were no significant differences between G_0 (pure tea system) and G_1 (intercropped with grafted ginkgo seedlings at a spacing of 10 m × 10 m) (Yaling Tian *et al.,* 2012).

MBC of maize-maize soil reached the highest and significant level compared with other treatments and that of soybean-maize and soybean-mixed was the lowest and had significant difference from other treatments. MBC of previous soybean soil was all lower

than that of previous maize soil. MBN of maize-mixed soil was the maximum of all cropping patterns and had significant difference from the others. Invertase activities of maize-maize and maize-soybean soils were the largest and showed significant difference from those of other treatments. Invertase activities of previous soybean soil were all lower than those of previous maize soil and were almost the same as catalase activities of the regular pattern (Yan Mu-Chun *et al.,* 2012).

Justin *et al.* (2013) determined the activities of soil dehydrogenase, acid phosphatase, alkaline phosphatase, and arylsulfatase under different land uses and cropping systems in the Almora region of Central Himalaya, India. All enzymes showed higher activity under undisturbed forest due to higher substrate availability and lowest activity under barren land uses due to lower organic matter content. The DHA activity under different land uses was observed to decrease in the order of natural oak forest > organic farming > fodder crop > soybean-wheat and barren.

Srilatha *et al.* (2013) opined that the activity of acid and alkaline phosphatase in soil at different growth stages of rice revealed that there was an increase in enzyme activity up to active growth stages of crop and later showed decrease. The activities of acid and alkaline phosphatase were significantly higher with application of 150% NPK followed by the treatment 100% NPK +FYM @ 10 t ha^{-1}. Phosphatase activity was at its peak at 60 days after transplanting stage.

Ullah *et al.* (2013) showed that the soil microbial biomass carbon (MBC), nitrogen (MBN), phosphorus (MBP) and soil enzymes such as dehydrogenase (DH) and alkaline phosphatase (AP) activities varied in all seasons. Overall, summer showed more soil MBC, MBN and MBP contents and relatively more DH and AP activities as compared to the other seasons. The soil MBC contents were higher under wheat–maize cropping system, while the soil MBN and MBP contents were higher under wheat–mungbean cropping systems in Kahuta areas. But the soil AP and DH activities were more pronounced under wheat-maize and wheat–mungbean cropping systems, respectively. We suggest that the inclusion of leguminous crops in cropping system is

more suitable for arid areas, which tend to sustain soil fertility and preserve soil microbial biomass.

Campos *et al.* (2014) showed that soil microbial biomass carbon (C) and basal respiration were significantly higher in middle part (MP): tropical cloud forest, grassland and upper part (UP): coniferous forest than in lower part (LP): tropical deciduous forest and sugarcane, whereas the microbial quotient (C_{mic}/C_{org}) was higher in LP and MP than in UP. Net N mineralization, ammonification, and nitrification rates were higher in UP than MP and LP. In LP, lower microbial biomass C, C_{mic}/C_{org}, and nitrification rates but higher ammonification and net N mineralization rates were observed in tropical deciduous forest than in sugarcane.

Qiong Liang *et al.* (2014) reported that the activity of dehydrogenase in bulk soil was significantly higher in the FYM treatment than those in mineral fertilizer and control in both 0 to 10 and 10 to 20 cm depths. It is attributed to higher content of organic matter that enhanced microbial activity and also application of FYM enhances soil quality by improving the ability of soils to perform nutrient cycling and transformation.

Urease activity in uncultivated soil ranged 1.49–2.26 μg g^{-1} h^{-1}, with the mean of 1.66 μg g^{-1} h^{-1} in 0–40 cm. The soil urease activity in root zone presented an increasing trend with the planting years. The weighted means were 1.76, 2.51 and 4.32 μg g^{-1} h^{-1}, respectively in the 3 transects, increased by 6.0%, 51.2% and 160.2%, relatively to the uncultivated soil (Zhang *et al.,* 2014).

Soil urease activity averaged over all cropping systems was unaffected by fertilizer P application rate in both 2011 and 2012. Averaged over three P rates, urease activity was not altered by intercropping over the two years with the exception of maize/soybean intercropping in 2011. At the individual P level, soil urease activity in maize/soybean and maize/turnip intercropping with zero P was enhanced by 18.1% and 19.3% and maize/chickpea intercropping receiving 80 kg P ha^{-1} showed a decrease of 28.1% in 2011, and maize/faba bean intercropping with zero P increased by 15.7% in 2012. At the individual P levels, soil acid phosphatase activity in maize/faba bean,

maize/soybean and maize/chickpea intercropping receiving 40 kg P ha^{-1} were 65.0%, 26.2% and 53.2% higher than in the monocrops and maize/turnip intercropping without P increased by 86.4% in 2011. Maize/soybean intercropping receiving 40 kg P ha^{-1} was 52.9% greater than the monocrops in 2012 (Zhi-Gang Wang *et al.,* 2014).

Peiyu Luo *et al.* (2015) noticed that organic fertilization significantly increased dehydrogenase activity after long-term application. Compared with mineral fertilizers, organic manures had significantly greater impact on dehydrogenase activity. The variation trend of dehydrogenase activity per SMBC was similar to that of SMBC and dehydrogenase activity. Compared with P sufficiency fertilization, P-deficiency fertilization significantly decreased dehydrogenase activity.

Dehydrogenase activity was significantly influenced by tree density under poplar + Indian mustard intercropping system during both the years. The dehydrogenase activity was not influenced by fertility levels during both the years. Dehydrogenase activity increased with increased tree densities and reached maximum (118 and 167 µg TPF g^{-1} day^{-1}) and significantly higher under 500 trees/ha density in 2008–09 and 2009–10, respectively, compared to sole crop in first year and sole crop, 250 and 1000 trees/ha densities in second year. The differences between sole crop and 1000 trees/ha and amongst 250, 500 and 1000 trees/ha in 2008-09 and between 250 and 1000 trees/ha densities in 2009–10 were not significant (Tara Bahadur Ghimire and Om Prakash Singh Bana, 2015).

The dehydrogenase activity in soil increased with increase in tree density and significantly higher (67.71 µg TPF day^{-1} g^{-1}soil) activity was recorded under 1000 trees/ha density. The alkaline phosphatase activity in soil increased significantly with successive increase in tree density and it was maximum (15.88 µg *p*-nitrophenol hr^{-1} g^{-1} soil) under 500 trees/ha as compared to all other densities except 1000 trees/ha. The maximum (5.09 µg *p*-nitrophenol hr^{-1} g^{-1} soil) and significantly higher acidic phosphatase activity was recorded under 500 trees/ha as compared to all other tree densities, followed by 1000, 250 trees/ha and sole crop with significant differences among them (Uthappa *et al.,* 2015).

Francisco *et al.* (2016) found that the highest MBC values were found in soils under agroforestry system and native vegetation, whereas the lowest MBC values were found in the soil under the *Andropogon* and *Panicum* plots. The highest MBN value was found in the *Brachiaria* plot than the other plots. The MBC/MBN ratio was highest in the agroforestry system and native vegetation. Acid phosphatase activity was significantly higher in soils under the agroforestry system. However, dehydrogenase activity was higher in the soil under the *Brachiaria* and *Cynodon* plots than in the other plots.

Gunes *et al. (*2007) revealed that biomass yield of peanut and barley was decreased by associated plant species as compared to their monoculture. Rhizosphere chemistry was strongly and differentially modified by the roots of peanut and barley and their mixed culture. In the mixed cropping of peanut/barley, intracellular alkaline and acid phosphatases, root secreted acid phosphatases acid phosphatases activity in rhizosphere and bulk soils were higher than that of monocultured barley. Furthermore, mixed cropping improved N and K nutrition of peanut plants, while Ca nutrition was negatively affected by mixed cropping.

Jinchuang Wang *et al.* (2017) reported that the soil microbial mass P (MBP) was significantly affected by land use. The highest value of MBP was measured in natural. After forest conversion, MBP was significantly decreased in young rubber and this parameter increased with the increasing rubber age. However, soil in agroforestry system had the lowest value among all forest stands. Soil acid phosphatase activity (APA) also varied with land use. APA was highest in natural forest, intermediate in mature rubber and agroforest stands, without significant difference between them and the lowest in young rubber stands.

Ramulu *et al.* (2017) reported that the SMB of nitrogen (μg g^{-1} soil) ranged from 20.1 under custard apple to 33.0 under custard apple + cowpea in 2012; 22.0 under custard apple to 34.4 under custard apple + cowpea in 2013 with mean of 25.6 and 27.3 in the two years, respectively. The increase in SMB nitrogen was due to an increase in the soil organic matter under intercropping systems and the reduced rate of leaching in the

soil profile. Higher SMB nitrogen was mainly contributed by the decomposition of leaf litter, root and crop residues.

Ravindra Kumar *et al.* (2017) reported that soil samples from rice–wheat cropping sequence of four different locations of Meerut and Bulandshare districts (U.P) showed that dehydrogenase activity in surface (0–15 cm) and subsurface soil (15–30 & 30–45) varied from 55 to 69, 25 to 31 and 12 to 15 µg TPF g^{-1} soil day^{-1} with an average value 62.75, 27.50 and 13.25 µg TPF g^{-1} soil day^{-1}.

The microbial biomass showed greater values in the cultivated land with multiple tree species as compared to other soils. Across the systems, the average microbial biomass carbon ranged from 178 µg g^{-1} (crop fields without tree/shrub species, OC) to 254 µg g^{-1} (in crop fields with multiple tree species C + mT), while microbial biomass nitrogen ranged from 15 µg g^{-1} (OC) to 40 µg g^{-1} (C + mT). These findings are possibly endorsed by the accumulation of more organic carbon under the cultivated land with multiple tree species (Kirtika Padalia *et al.,* 2018).

Luying Sun *et al.* (2018) reported that agricultural practices significantly affected urease activity. Integrated agricultural practice (IP) resulted in higher urease activity than did conventional practice (CP) and the highest activity was observed in August. Sampling time significantly affected protease activity. June exhibited the highest protease activity and August the lowest. Invertase activity was affected by management practice and sampling time. IP significantly enhanced invertase activity. The highest invertase activity was observed in October compared and the lowest in June. β-glucosidase activity was affected by sampling time. The highest β-glucosidase activity was measured under IP in October and the lowest activity was measured under CP in August. Acid phosphatase activity was affected by both management practice and sampling time. Compared with CP, acid phosphatase activity under IP was significantly higher. IP resulted in the highest acid phosphatase activity in October. In CP, the lowest acid phosphatase activity was observed in June.

Sheoran *et al.* (2018) studied the enzyme activities at different locations in Haryana state (India) and reported that the soil dehydrogenase activity in different locations varied between 18.5 to 46.0 µg TPF g^{-1} soil 24 hr^{-1} in conventional farming while it ranged from 23.8 to 78.6 µg TPF g^{-1} soil 24 hr^{-1} under organic farming. The values of phosphatase activity varies from 132.6 to 453.1 µg PNP g^{-1} soil hr^{-1} among different locations under conventional system of farming while it ranged from 151.8 to 642.8 µg PNP g^{-1} soil hr^{-1} under organic system of farming.

From the above literature it can be concluded that, agri–horti, agro-forestry, agri-siliviculture, green manure and FYM practices have been found to improve the physical, chemical and biological properties of the soil especially the bulk density, water holding capacity, penetration resistance, infiltration rate, porosity, soil, organic carbon content, pH, electrical conductivity, cation exchange capacity, nitrogen, phosphorus and potassium. The type, number and activity of microorganisms have been reported to be influenced by the application of organic manures, leaf litter and previous residues because of adding more biomass to soil.

2.3 Effect of agri–horticulture systems on carbon dynamics in soil

Sustaining soil organic carbon is important for cycling plant nutrients and improving the physical, chemical and biological properties of a soil to sustain crop productivity (Lal *et al.,* 1999). Soil organic matter is one of the most important constituents of soils as it influences the plant growth directly as well as indirectly. Indirectly, it improves the chemical and physical conditions of soils by increasing cation exchange capacity, buffering capacity, aggregation, aeration and water retention (Bongiovanni and Lobartini, 2006). Soil carbon exists in different forms which make up the total carbon of the soil. So, we have made an effort to collect the different reviews on different fractions of carbon and presented in this section.

2.3.1 Organic carbon

Soil organic carbon is essential for enhancing soil quality, sustaining and improving food production, maintaining clean water and reducing increased CO_2 in the

atmosphere, whereas its inorganic counterpart is the cause of organic carbon decomposition, developing salinity, restricting root proliferation (Eswaran and Van Den Berge, 1992; Pal *et al*., 1999) and immobilizing soil plasma (Buol *et al*., 1980).

Naturally occurring organic carbon forms are derived from the decomposition of plants and animals. Studies have shown that an increase in SOC levels is directly related to the amount of organic residues added to the soils (Rasmussen *et al.,* 1980) and fertilizer and manure application (Hartwig and Ammon, 2002). The SOC in agricultural soils has a turnover time from decades to centuries, thus the gross contents of SOC change very slowly (Stevenson, 1994).

The global soil organic carbon pool, estimated at 1550 Pg C in the top 100 cm, is an important component of the global carbon cycle as it contains more carbon than the atmosphere (780 Pg C) and biosphere (620 Pg C) combined (Batjes, 1996).

The SOC content of surface soils is sensitive to human interference and changes in land-use and soil management to protect or increase the existing soil C pool by sequestration of C from the atmosphere could become crucial in terms of future policies to mitigate the global greenhouse effect (IPCC, 2000).

Soils of tea gardens and forest areas recorded their highest organic carbon in the surface horizons and then decreased sharply with depth. However, the depth distribution of organic carbon in the soils of cultivated lands did not follow any regular trend. On the basis of organic carbon content in the surface samples, all the pedons under tea gardens and forest areas were rated as high (> 7.5 g kg^{-1}), and among the twelve pedons from cultivated area, three as low as 5.0 g kg^{-1}), six as medium (5.0-7.5 g kg^{-1}) and three as high (Saha *et al.,* 2000).

Land use changes have been frequently reported as the most important driving force for soil organic carbon dynamics, that impacts the SOC dynamics by changing the rates of carbon inputs, type of vegetation, rate of SOC decomposition and the magnitude of various carbon pools in soil (Shepherd *et al.,* 2001). SOC is the second largest carbon pool on the surface of the earth after the oceans (Swift, 2001). The active pools generally

contribute about 10–20 per cent towards total soil organic matter, whereas the stable or passive pools have 50–90 per cent contribution towards total soil organic matter (Brady and Weil, 2002) and the possibility of increasing the OC content of the soil through changing agronomic management practices may play a role in combating climate change (Lal, 2002).

Bhattacharyya *et al.* (2004) observed that increase in SOC with the decrease of soil pH. It has been reported that clay and organic matter remain as a complex form known as clay-humus complexes. SIC present, mostly in the form of calcium carbonate, also has a cementing effect in binding inorganic colloids; mainly in binding the clay–fractions. Generally in soil, organic carbon content decreases with increase in soil depth. The presence of organic matter at lower depths of soil is due to the downward movement of soluble OM originating from top soil plays an important role in sustaining subsoil microbial activity (Chantigny, 2003) which in turn sustains microbial biomass carbon.

Lettens *et al.* (2004) observed that the change of the SOC in the upper 100 cm of mineral soil follows a logarithmic decline with increasing depth, useful for the extrapolation of SOC of surface layers to deeper layers whereas SIC values are strongly related to the geological soil characteristics and increase linearly with depth.

Increase in SOC results in increased dissolution and reprecipitation of carbonates as a result of SOC influence on microbial respiration yielding CO_2, as well as Ca^{2+} and Mg^{2+} (Bronick and Lal, 2005).

An experiment containing three treatments (2, 15 and 25–year old plantations) was conducted. Results revealed that soil carbon (C) to a depth of 15 cm varied between treatments (2 years: 22.6 Mg C ha^{-1}; 15 years: 17.6 Mg C ha^{-1}; 25 years: 18.2 Mg C ha^{-1}) with a significant difference between 2– and 15– and 2– and 25–year–old treatments. Total soil nitrogen in the top 15 cm varied between 1.09 and 1.25 Mg N ha^{-1} but no significant differences were noted between treatments (Isaac *et al.,* 2005).

Jimenez *et al.* (2007) evaluated the soil organic carbon pool in a plantation with native tree species established in a degraded pasture of the Caribbean lowlands of Costa

Rica. Average SOC concentration ranged from 44.9 to 55.2 g kg^{-1} (0–10 cm) and decreased with depth up to 12.7-16.8 g kg^{-1} (40–50 cm). The highest SOC pool was measured under *Hieronyma alchorneoides* and *Vochysia guatemalensis*, *i.e.* 131.9 and 119.2 Mg C ha^{-1}, respectively, whereas in the pasture it was 115.6 Mg C ha^{-1}. The SOC pool has not changed significantly under the tree species evaluated 14 years after establishment.

Tan *et al*., (2007) reported that the dynamics of SOC with change in land use and management can better be explained by the way C is allocated in different fractions of soil organic matter.

Factors including vegetation coverage, the amount of litter fall and root impact, and disturbance or management regime can contribute to the significant variation of surface soil SOC across different land uses (Chen *et al.,* 2007).

According to Smith (2007), carbon inputs to the soil are largely determined by the land use, with forest systems tending to have the largest input of C to the soil (inputs all year round) and often this material is also the most recalcitrant. The smallest input of C is often found in croplands which have inputs only when there is a crop growing and where the C inputs are among the most labile.

The soil organic carbon pool stores an estimated 1500 Pg C in the first meter of soil, which is more than C contained both in the atmosphere (roughly 800 Pg C) and terrestrial vegetation (500 Pg C). The phenomena of SOC reservoir is not static, but is constantly cycling between the different global carbon pools in various molecular forms (Rattan Lal, 2008).

It is essential to restore degraded soils through enhancing the soil organic pool and improving the below-ground environment for food security. In this situation, the maintenances of soil organic pools are a major challenge in tropical climates (Lal, 2009).

Jiao *et al*. (2009) reported that the SOC contents for the soil of 0–10 cm, 10–20 cm and 20-30 cm was 3.37, 2.89 and 2.11% in the grassland and 2.55, 2.27 and 1.55 in the forest soils.

Srinivasarao *et al*. (2009) reported that soil C content mostly depends on climate, soil type and land use. *Vertisols* and associated soils contained greater C stocks, followed by *Inceptisols*, *Alfisols*, *Aridisols***.** In general, SOC content was greater than inorganic C content in *Alfisols* and *Aridisols* and inorganic C was larger than organic C in *Vertisols* and *Inceptisols*.

Alan (2010) reported that depth distribution of soil organic carbon was significantly affected by land use category. At 5 and 10 cm depths, soil organic carbon concentration was greater under pastureland and forestland than under cropland. At 20, 30, and 40 cm depths, soil organic carbon concentration was greater under pastureland than under forestland and cropland. At 50 to 100 cm depths, soil organic carbon concentration was greater under pastureland than under cropland; forestland was not different from either of the extremes.

The combination use of organic manure and mineral fertilizers not only enhance the sequestration of SOC to some further extent, but also improve the quality of SOM by aggregation effect. Therefore, good soil management practices should preferably include organic manure application to maintain better soil structure and SOM levels in the *Mollisol*. The chemical protection over SOC is limited in large class aggregates, but physical protection plays a major role for the sequestration of the increased SOC in the Chinese *Mollisol*. Therefore, when SOC is sequestered along with long-term organic manure application, there is a shift of SOC from the silt + clay fraction to large aggregates (Chen *et al.,* 2010).

Guangyu *et al.* (2010) reported that the SOC content in undisturbed wetland and cultivated lowland rice fields had a marked decrease from 0–10 cm to 40–60 cm and a less change downward. In 0–10 cm layer, there was a significant difference in SOC content, with the sequence of undisturbed wetland >lowland rice field reclaimed for 25

years > lowland rice field reclaimed for 10 years. Compared with that in undisturbed wetland, the SOC content in the 0–10 cm layer in the lowland rice fields having been reclaimed for 10 and 25 years was decreased by 49.3 and 14.3%, respectively.

Most of soils under rainfed agriculture are depleted of their SOC and nutrient pools because of extractive farming practices based on nutrient or nutrient mining. Mulch farming, cover cropping, INM, including the use of compost and other bio-fertilizers helps in enhancing carbon pool in soils, especially in dryland agriculture (Lal, 2010).

Rekha *et al.* (2010) reported that the soil organic carbon concentration was 0.96% at 0–15 cm soil depth. There was decrease in concentration of soil carbon with increase in soil depth. The soil carbon (Mg C ha^{-1}) at different soil depths was: 17.093 (0–15 cm), 9.906 (15–30 cm), 8.008 (30–45 cm), 4.416 (45–60 cm) and 8.635 (60–100 cm).

Wang *et al.* (2010) studied that the SOC content in the 0-3.0 m soil profile was significantly different among landscape types from forest to desert. On average, the order of decrease is in accordance with the MAP of each landscape: forest (15.04 g kg^{-1})> grassland (1.33 g kg^{-1})> shrub-grassland (0.92 g kg^{-1})> shrub land desert (0.42 g kg^{-1})> desert (0.25 g kg^{-1}). SOC concentration decreased with increasing soil depth under all land-use types with significant difference across different soil depth.

Chauhan *et at.* (2011) reported that a decreasing trend in soil organic carbon (SOC) was observed with soil depth in all the poplar plantations and plots without poplar trees. However, the content was low in control plot than under different age poplar plantations at three different soil layers (0.32% under control and 0.42% under fifth year plantation). The concentration was significantly high in surface soil layer (0–15 cm) than sub-surface depths of 15–30 and 30–60 cm. The total organic carbon concentration ranged from 6.91 to 8.44 mg/ha under treeless plot to fifth year plantation, respectively with an increase of 22.14 percent under fifth year plantation than the tree less control plot.

Soil of world's agro–ecosystem are depleted of their SOC stock by 25–75 per cent depending on climate, soil type and historic management, magnitude of this loss may be 10-50 Mg C ha^{-1} (Lal, 2011).

Singh *et al.* (2011) reported that 69% of soil carbon in the profile was confined to the upper 40 cm soil layer where C stock ranged from 8.5 to 15.2 t C ha^{-1}.

Baljit Singh and Sharma (2012) reported that the increase in OC concentration under trees from control was the highest in the surface soil depth (0–15 cm). Amongst different soil depths, the average OC concentration was the highest in surface soil depth (5.68 g kg^{-1}) and the lowest in 90-120 cm depth (0.76 g kg^{-1}). Higher build-up of soil organic carbon on surface layers under the tree species may be attributed to the accumulation of litterfall of tree species on soil surface.

Gaur and Gupta (2012) in a study on impact of agroforestry systems on C sequestration and soil physical properties in Haryana (India), reported that soil OC pool in the *Populus deltoides* based agroforestry system (wheat as intercrop) was greater. They found that C storage in water stable soil aggregates was directly related to soil organic C and that the silt and clay fractions of soil microaggregates (<53 μm) protected a large fraction of SOC thus improving soil health together with climate change mitigation.

Ghosh *et al.* (2012) showed that continuous application of organic amendments resulted in the highest increase of SOC content (10.4%) over control. Among the cropping systems, rice-wheat-mung bean had the highest SOC content in surface depth, which was 6% higher than the rice-wheat system. The analysed data detected significant variation in depth-wise distribution of SOC with cropping system and nutrient management practices. The SOC content decreased up to 43% at 20–40 cm depth and further 22% at 40–60 cm depth.

Lakaria *et al.* (2012) observed that the SOC content ranged between 2.2 and 24.8 g kg^{-1} under different land use systems. The highest organic carbon content was recorded in the forest and horticulture land use systems which was attributed to the long term addition of carbon over more than 25–50 years in these soils coupled with minimum

physical disturbance to surface soil as compared to agriculture and agri–horticulture land use systems.

Park *et al.* (2012) reported that the mean C concentration of the whole aggregate size fractions was 2.82%, 1.77%, and 1.42% in the *P. rigida* plantation and 4.54%, 2.60%, and 1.50% in the *L. kaempferi* plantation at depths of 0–10 cm, 10–20 cm and 20–30 cm, respectively. The soil C content within the 30 cm of depth was 47.69 Mg ha^{-1} in the *P. rigida* plantation and 61.49 Mg ha^{-1} in the *L. kaempferi* plantation.

Srinivasarao *et al.* (2012) opined that application of farmyard manure (FYM) without and with mineral fertilizers increased C input and SOC concentration and stock. In comparison with the control, the 100% organic (FYM) treatment had significantly higher profile SOC (27.5 Mg ha^{-1}), and more C build up (55.0%) and C sequestration (6.6 Mg C ha^{-1}) to 1 m depth. The SOC stock and rate of sequestration were positively correlated with cumulative C input, and with sustainable yield index (SYI) of upland rice and lentil.

Total SOC stocks were low (8 to 20 Mg C·ha^{-1} within upper 0.2 m depth, 20 to 64 Mg C·ha^{-1} within upper 1 m depth) and were significantly lower in sandy soils than in sandy clayey soils and lower (approximately 27–37%) in groundnut fields than in savanna soils (Assize Toure *et al.,* 2013).

Among the different land use systems, the SOC followed the order as forest > barren land >agricultural land. The barren land showed higher SOC than agricultural land. Lower SOC in agricultural land was attributed to highly disturbed due to tillage farming and heavy uses of chemical fertilizers whereas the barren land was less disturbed with scrubby vegetation (Bhandari and Bam, 2013).

Total soil organic matter (SOM) concentrations in the 0-10 cm soil layer differed significantly among land uses and followed the order: integrated coconut > native forest > citrus = conventional coconut. Considering the soil of the native forest as a reference, the integrated coconut orchard showed an increase in SOM of approximately 37%. On the other hand, in the conventional coconut and citrus orchards the SOM concentrations

were reduced by almost 40%. This was mainly because the different soil uses and managements affected the inputs of organic residues (Daniele *et al.,* 2013).

The carbon pool in poplar-plantation soils was positively correlated to the time of use at the three soil depths studied (0–20, 20–50, and 50–100 cm), the mean annual increase being 1.16 Mg C ha^{-1} $year^{-1}$. Poplar-plantation soils also increased the total carbon content in a more effective way because the duration of use was also correlated with the most recalcitrant carbon forms. Therefore, it is concluded that land-use change from corn crops to poplar-plantation soils is economically profitable as well as positive both for the total organic-carbon pool as well as for the efficiency of carbon sequestration by the increase of non-oxidizable forms in the soil (Sierra *et al.,* 2013).

Sheikh Iqbal and Tiwari, (2013) reported that among different land use systems the highest soil organic carbon pool was found in forestland (166.88 t ha^{-1}), followed by grassland (95.54 t ha^{-1}), agricultural land (75.70 t ha^{-1}), and least was recorded in the wasteland (57.05 t ha^{-1}). The overall percentage share of total SOC pools occupied under different land uses found in Achanakmar (Chhattisgarh) were: forest land, both dense and open (81%), agricultural land (17%), grassland (01%), and wasteland (01%). The present study reveals that forest land use has a maximum potential in sequestration of soil organic carbon pool compared to other land uses in Achanakmar (Chhattisgarh).

Srinivasarao *et al.* (2013) concluded that in the rainfed arid, semiarid and sub humid regions of India, next to poor rain water management, depletion of nutrients caused by low SOC stock is an important cause of soil degradation resulting in poor soil physical quality, loss of favourable biology and occurrence of multiple nutrient deficiencies resulting in low productivity. Improving SOC stock is, therefore, crucial for sustaining soil quality and enhancing agricultural productivity particularly from the rainfed regions.

Yong-Tao Zhang *et al.* (2013) studied the SOM in surface soils (0–10 cm) of different types of land use and results revealed that the contents in grassland were the highest in the order of grassland (0.752%) > farmland (0.663%) > woodland (0.598%) >

reed-bed (0.1415%). SOM in natural wetlands was mainly from the decomposition of animal and plant residues. The main outputs of SOM included decomposition, mineralization and erosion.

Zubrzycki *et al.* (2013) studied organic carbon stocks in soils of the Lena River Delta (Arctic). The mean SOC stocks for the upper 1 m of soils were estimated at 29 kg m^{-1}± 10 kg m^{-1} and at 14 kg m^{-1}±7 kg m^{-1}, respectively. For the depth of 1 m, the total SOC pool of the Holocene river terrace was estimated at 121 Tg ± 43 Tg, and the SOC pool of the active floodplains was estimated at 120 Tg ± 66 Tg.

There was significant difference in SOC in different land use pattern. In this study the highest organic carbon was found under agroforestry system (1.438%) and the lowest organic carbon was found under fallow land (0.124% for 20–30 cm). Cropland and grassland organic carbon were found respectively 0.63% and 0.39% for top soil respectively. It is well known that tree species strongly influence the forest floor in terms of C stock and chemistry, it also regulate annual carbon turn over (Asif Iqbal *et al.,* 2014).

Total SOC increased with treatment: no fertilizer < inorganic fertilizers alone < farmyard manure. SOC increased by 19% in the inorganic fertilizer treatments relative to the control. However, the SOC concentration in the farmyard manure treatment was almost twice of that in the no-fertilizer treatment. SOC concentration was the highest in the MNPK treatment and lowest in the IN treatment. This result indicated that the long term application of inorganic fertilizers had no significant effect on SOC accumulation in tilled cropping systems, in which crop residue and roots were removed. By contrast, the SOC concentration in the manure treatments increased significantly (Liang Cheng-Hua *et al*., 2014).

Tshering Dorji *et al.* (2014) reported that the SOC density under agricultural lands (34%) was more homogeneously distributed down the profiles than forests (39%), grasslands (59%) and shrublands (43%). However, when forests, shrublands and

grasslands were compared, forests had relatively large and more uniform distribution of SOC density down the profiles.

Among different land use systems, forest system (87.29 Mg ha^{-1}) shows the highest organic C stocks, followed by fodder (60.03 Mg ha^{-1}), paddy (57.12 Mg ha^{-1}), maize (52.12 Mg ha^{-1}), chilli (49.50 Mg ha^{-1}), red gram (48.44 Mg ha^{-1}), intercrop (45.69 Mg ha^{-1}), cotton (44.98 Mg ha^{-1}), permanent fallow (44.81 Mg ha-1) and is lowest in case of castor (36.86 Mg ha^{-1}) system. Among different soil organic carbon stock was highest in *Alfisols* (52.84 Mg ha^{-1}) followed by *Inceptisols* (51.26 Mg ha^{-1}) and *Vertisols* and associated soils (49.33 Mg ha^{-1}) (Venkanna *et al.,* 2014).

Adugna and Abegaz (2015) revealed that organic matter was the highest (9.0% in topsoil and 4.2% in subsoil) under forestland and was the lowest (3.0% in topsoil and 2.0% in subsoil) under bush land. The percentage changes in organic matter content of subsoil from topsoil were decreasing in all land uses. This implies that the surface soil layer is the most biologically active of the soil profile. The litter on the soil surface beneath different canopy layers and high biomass production caused high biological activity in the topsoil layer.

Babbu Singh Brar *et al*. (2015) reported that the SOC increased with continuous application of FYM and inorganic fertilizers for 36 years among all treatments. The SOC ranged from 3.08 g kg^{-1} to 5.20 g kg^{-1} in the 0–15 cm layer for different treatments in 2007. The soil fertility in 100% NPK + FYM was in medium range as SOC ranged between 4 and 7.5 g kg^{-1} whereas all other fertilizer treatments were still in low SOC range. The SOC increased to 3.34 g kg^{-1} with application of 100% N, 3.52 g kg^{-1} with 100% NP, 3.71 g kg^{-1} with 100% NPK and 5.20 g kg^{-1} with 100% NPK+FYM compared to the non-treated control (3.08 g kg^{-1}).

Soil organic carbon was higher in agroforestry systems than in the sole agriculture and tree plots at six years age. SOC increased by 80% in *Cordia myxa* + *Colophospermum mopane* and by 73% in *Zizyphus mauritiana* + *Prosopis cineraria*

combinations in 2012 than in 2006. The increase in SOC was 67% in *P. cineraria* and 63% in *C. mopane* combinations (Bilas Singh and Singh, 2015).

Remi Cardinael *et al.* (2015) studied an experiment having hybrid walnuts + wheat and control plots (wheat as sole crop) and showed that for 0-10 cm, SOC concentration doubled in the tree row (21.6±0.8 mg C g^{-1}) compared to the inter-row (9.8 ± 0.1 mg C g^{-1}) and to the control (9.3 ± 0.1 mg C g^{-1}), whereas the latter two were not significantly different. SOC concentration was significantly higher in the tree row than in the control plot to 120 cm soil depth, except in the 50-70 cm soil layer where no difference was observed. SOC concentration was significantly higher in the tree row than in the inter-row to 30 cm soil depth. At the plot scale, cumulated SOC stocks in the agroforestry plot were significantly higher than in the control plot at all depths. For an equivalent soil mass of 4000 Mg ha^{-1} (to 26-29 cm depth), SOC stocks were 40.3 ± 0.5 Mg C ha^{-1} and 35.8 ± 0.2 Mg C ha^{-1} in the agroforestry and in the control, respectively.

The mean organic carbon content increased sequentially and significantly with increase in number of poplar cutting cycles in surface layer (0–15 cm) except between three cutting cycles and two cutting cycles where the increase was non-significant. The higher organic carbon in surface soil may be attributed to greater input of C through litterfall and greater root biomass addition of poplar. The organic matter after decomposition adds a significant amount of carbon to the soil (Shehnaz Sharma *et al.,* 2015).

Bahilu Bezabih *et al.* (2016) reported that soil organic carbon stocks were significantly influenced by slope position, land use types and soil depth. The average value of soil organic carbon stocks were 17.05, 18.97 and 13.15 t/ha for lower, middle and upper slope positions respectively. The result revealed that soil organic carbon stocks were significantly decreased from lower to upper slope positions. Regarding to land use types, the average SOC stocks were 13.50, 18.65, 17.03 t/ha for cultivated, enset woody land, respectively. Among all land uses and soil depths the lowest mean soil organic carbon (1.37% or 9.14 t/ha) in the sub layer of cultivated land and the highest (3.93% or 22.59 t/ha) in the upper soil layer of enset farm land.

The continuous alfalfa system had the highest recovery of organic carbon. Recovery mainly occurred in the >0.053 mm aggregate size class, which varied with cropping system. The continuous alfalfa system led to the accumulation of OC and N in the 0.25–2.0 and 0.053–0.25 mm size classes and the continuous wheat and rotation systems led to the accumulation of OC and N in the >2 mm size class. The accumulated OC and N were relatively more stable in the continuous alfalfa system than in the continuous wheat and rotation systems (Jiashu Chu *et al.*, 2016).

The soil organic carbon content in the farmland and grassland of Tibet decreased with increase in soil depth. The SOC contents at the 0–5 and 40–50 cm grassland layers were 7.83±5.28 and 2.73±0.94 g/kg, respectively, corresponding to a 65.13% reduction. The SOC content at the 0–5 cm depth was significantly different from those in all the layers except at 5–10 cm. The variability of the SOC in the vertical profile of the grassland was larger than that in the farmland, with CVs of 38.07% and 18.10%, respectively (Liu Heman *et al.,* 2016).

Nancy Loria *et al.* (2016) reported that soil organic carbon ranged from 7.34 to 9.70 g kg^{-1} and 5.41 to 7.41 g kg^{-1} in surface and subsurface soils, respectively. The cropping system wise trend of soil organic carbon in surface soil was; fruit (9.70 g kg^{-1}) > agroforestry (9.42 g kg^{-1}) > cereal (8.75 g kg^{-1}) > uncultivated (8.06 g kg^{-1}) > vegetable (7.34 g kg^{-1}). Relatively higher SOC contents of surface soils as compared to subsurface ones may be attributed to accumulation of root and plant biomass.

Wei Zhao *et al.* (2016) studied the SOC in different vegetation cover and reported that in general, SOC of the samples on the shady slope (2.1–6.2, 1.8–8.6, 2.1–5.3 g kg^{-1} for grass, shrub and forest, respectively) was higher than that on the sunny slope (2.1–4.2, 1.9–6.7, 1.9–4.1 g kg^{-1} for grass, shrub, and forest, respectively). The SOC under different vegetation covers decreased sharply along soil depth in the top 0–50 cm of the soil layer and kept stable values around 2 g kg^{-1} over the 50–200 cm depth. For different types of vegetation, the SOC in the 0–50 cm top layer decreased in the order of shrub≥grass>forest for the shady slope and shrub>grass≥forest for the sunny slope.

All soil horizon of the arid region contained lower SOC content (decreasing by depth) than the semi-arid and dry sub-humid regions in Iran. The deepest pedons were observed in the dry sub-humid region with high SOC content even in the deepest horizons (Alireza Raheb *et al.,* 2017).

Dar *et al.* (2017) reported that the organic carbon in the surface layer (0–25 cm) varied from 1.28 to 2.36, 1.14 to 2.21 and 0.66 to 1.72 per cent, in high, mid and low altitudes, respectively, with an overall range and mean value of 0.66 to 2.36 per cent and 1.54 per cent in surface soil respectively. Whereas, in subsurface layer (25–50 cm) organic carbon ranged from 1.02 to 1.56, 0.99 to 1.49 and 0.54 to 1.56 per cent in high, mid and low altitudes, respectively, With an overall range and mean value of 0.54 to 1.56 per cent and 1.10 per cent in subsurface soil respectively.

Maximum improvement in the soil organic carbon content throughout the soil depths (0–15, 15–30 and 30–45 cm) was recorded to be as 0.59%, 0.55% and 0.46% respectively under guava + banana intercropping system, which was statistically superior than rest other intercropping system. The increase in higher SOC of soil under the above intercropping systems might be due to the decomposition of bio-mass and comparatively less undisturbed top soil which results to less oxidation of SOC as compared to sole guava (Saswati Ghosh *et al.,* 2017).

Shi *et al.* (2017) studied the SOC in soil samples collected at 0–20, 20–40, 40–60, 60–80 and 80–100 cm from 24 profiles in North China Plain and the results revealed that there was a wider range of SOC content in the surface (5–15 g C kg^{-1}) relative to the sub–soils (1–6 g C kg^{-1}). Apparently, SOC content declined dramatically from 0 to 20 to 20–40 cm and then changed little below. There was a significant difference in SOC between 0 and 20 cm (8.4–10.5 g C kg^{-1}) and 20–100 cm (2.2–4.8 g C kg^{-1}).

Yuxin Tong *et al*. (2017) found that soil organic carbon in C–C system (corn monocropping) increased from 13.8 to 15.5 g kg^{-1} (+12.3%), but decreased from 35.8 to 22.2 g kg^{-1} (-38.0%) in the S–S (soybean monocropping) and from 23.5 to 20.3 g kg^{-1} (-13.6%) in the S–C system (break system). In S–C group, when the ratio of corn/soybean

greater or equal to 1, no significant different SOC changes found between 2005 and 2014. When the ratio of corn/soybean was less than 1, the SOC significantly decreased from 26.3 g kg^{-1} in 2005 to 19.0 g kg^{-1} in 2014.

The mean SOC declined from 4.82 g C/100 g soil at 0–10 cm to 3.17 g C/100 g soil at 10–20 cm in a silvo–pastoral experiment. The value for the pasture (4.50 g C/100 g soil) was greater than that for the silvo–pasture (3.54 g C/100 g soil) at 0–20 cm. The quantity of SOC per 10 cm interval declined with depth. Calculating SOC on the basis of a fixed depth, there was no significant effect of land use on soil C storage, which ranged from 85.1 Mg C ha^{-1} in the pasture to 78.1 Mg C ha^{-1} and 76.1 Mg C ha^{-1} in the silvo–pasture and woodland, respectively (Dario Fornara *et al.,* 2018).

Soil organic carbon concentration from forestry to cropland was ranged from 2.95 to 5.00 g kg^{-1} soil in the 0–15 cm soil depth. The highest concentration of SOC was in the forestry (5.00 g kg^{-1}) followed by agro-forestry (4.32 g kg^{-1}), grassland (3.14 g kg^{-1}) and cropland (2.95 g kg^{-1}). Irrespective of the land-use, SOC concentration decreased with depth and ranged from 1.05 to 2.91 g kg^{-1} in 15–30 cm, 0.33 to 2.06 g kg^{-1} in 30–60 cm and 0.36 to 2.00 g kg^{-1} in 60–90 cm depth (Rajwinder Kaur *et al.,* 2018).

The mean SOC contents in the 0-20 cm layers of the cropland (4.35 g kg^{-1}) showed significant difference with those of the shrubland (6.25 g kg^{-1}) and woodland (5.76 g kg^{-1}), but had no significant differences with grassland (5.54 g kg^{-1}). However, the SOC contents in the 200–300 cm layers of cropland (1.49 g kg^{-1}) showed significant difference only with those of woodland (2.01 g kg^{-1}) sites. The differences of SOC contents among the seven sites in each land use type also decreased with increasing depth, and the order of decreasing degree was in accordance with that of the SOC content, which was shrubland >woodland > grassland > cropland (Xiaoyang Han *et al.,* 2018).

2.3.2 Inorganic carbon

Inorganic carbon forms are derived from geologic or soil parent material sources. Inorganic carbon forms are present in soils and sediments typically as carbonates. The

global SIC pool was estimated at approximately 700-1700 Pg C in upper 1 m depth (Eswaran *et al.,* 1995, 2000) with a mean value of 950 Pg C (Lal, 2004).

Kumar *et al.* (1998) studied the soil profile of canopies of *Acacia nilotica*, *Dalbergia sissoo*, *Eucalyptus tereticornis*, *Populus deltoides* and cultivated field. They reported that no systematic trend with depth was observed regarding the $CaCO_3$ distribution in these soils. Higher or lower content of $CaCO_3$ in deeper layers may be because of carbonaceous nature of parent material.

After studying the soil inorganic carbon storage pattern, Mi *et al.* (2008) reported that the soils inorganic C increased with increase in soil depth. They observed that contents of SIC may increase with depth in forest, meadow, shrubland and cropland as a result of leaching and SOC accumulation.

Haibin Wu *et al.* (2009) studied the changes in SIC by means of three different land use conditions in China and found that there was a sequential increasing loss in SIC content in paddy soils, non-irrigated fields and irrigated fields. They indicated that SIC storage loss was approximately 0.2 Pg C for paddy soils, 0.6 Pg C for irrigated fields, and 0.8 Pg C for the non-irrigated fields. Non-irrigated fields had the largest SIC loss mainly due to its large expanse in area (approximately 53% of all cultivated surfaces).

Rekha *et al.* (2010) reported that there were significant variations in quantity and vertical distribution of SIC. The soil inorganic carbon stock at different soil depths in the tree plantation was (Mg ha^{-1}): 1.404 (30–45 cm), 5.662 (45–60 cm) and 21.632 (60–100 cm).

Wang *et al.* (2010) have seen that the SIC content is also remarkably different along the precipitation gradient from forest to desert, but with a trend opposite to SOC: on average over the whole profile, forest (0.16 g kg^{-1}) <grassland (0.25 g kg^{-1}) <shrub-grassland (0.57 g kg^{-1}) <shrub desert (1.86 g kg^{-1}) <desert (2.89 g kg^{-1}). Wissing *et al.* (2011) has observed an increase in inorganic C below the plough layer.

Venkanna *et al.* (2014) reported that among different soil orders, soil inorganic carbon stock was highest in Vertisols and associated soil (22.9 Mg ha^{-1}) followed by Inceptisols (17.5 Mg ha^{-1}) and Alfisols (12.4 Mg ha^{-1}). The inorganic carbon concentration is highest in cotton, intercrop, red gram, fodder, maize, permanent fallow, paddy, chilli, castor and is lowest in forest system.

Weiguo Liu *et al.* (2014) studied SIC distribution in soil profile of three sites namely; farmland (FL), grassland restored for 12 years (RG–1) and grassland restored for 22 years (RG–2). The SIC content was significantly lower in the top 80 cm in RG–1 and RG–2 than in FL, but showed little variance at depths of 80–200 cm among the study sites. It illustrated that the portion of carbonate was most likely released to the atmosphere as CO_2 temporarily due to soil acidification and the increase of soil moisture in restored grassland. Their results indicate that the SIC storage deceases in the restored grassland in situ probably due to the decrease of soil pH and the increase in soil water content. The SIC plays an important role when assessing the capacity of carbon sequestration with vegetation restoration in the semi-arid CLP.

Wen-Feng Tan *et al.* (2014) studied the SIC density in different land use systems like grassland, farmland and woodland. According to them the SIC density follows the sequence: grassland≈farmland>woodland in all layers. In grassland relatively less carbonate leaching occurs due to the low precipitation and low temperature. Agronomic practices and conventional tillage of farmlands lead to processes that promote mineralization of soil organic matter and weathering of soil minerals. The soil organic carbon transforms from $C_{org.} \rightarrow CO_2 \rightarrow HCO_3 \rightarrow CaCO_3$ and weathering of soil minerals benefits the exchange of calcium in soils. In woodland intensive carbonate leaching occurs due to abundant rainfall and high temperatures. Although woodland is favorable for accumulation of organic matter, the many root exudates promote dissolution of carbonate and this leads to a lower SIC density for woodland than for grassland or farmland.

Among four horticultural land uses namely, guava (*Psidium guajava*), litchi (*Litchi chinensis*), mango (*Mangifera indica*) and jamun (*Syzygium cumini*), $CaCO_3$

content was highest at lower soil depths of the studied land uses except guava. Results showed that the $CaCO_3$ content was >1.5% for all the consequent soil layers under litchi plantation (1.49 to 1.93%) and at 40-60 cm depth under jamun plantation. Contrarily, <1.5% $CaCO_3$ content was observed at all soil layers under mango, guava and surface layer of jamun orchard. Higher amount of calcium carbonate at lower depths might be due to the process of leaching of calcium carbonate and subsequently precipitation at lower depths (Ashim Datta *et al.,* 2015).

Shehnaz Sharma *et al.* (2015) reported that among poplar cutting cycles soil inorganic carbon did not vary significantly at all the three soil layers. However, it was highest in rice-wheat sequence and also increased with soil depth. Leaching of soil carbonates might be the reason of enhanced SIC in lower depths in rice-wheat.

In a long term fertilizer experiment, it was reported that at 0–15cm depth of soil, significantly lower soil inorganic carbon was noticed in the 10 t of FYM ha^{-1} (9.48 g kg^{-1}) over maize residue at 5 t ha^{-1} (16.60 g kg^{-1}). Finger millet grown in mono cropping had significantly higher SIC (15.35 g kg^{-1}) than legume rotation (10.73 g kg^{-1}). SIC was significantly higher in 100 per cent recommended dose of fertilizer (17.75 g kg^{-1}) whereas only organic matter source has recorded the significantly lower value (9.50 g kg^{-1}). Irrespective of the treatments, the SIC content decreased with soil depth (Ashoka, 2016).

SIC on the shady slope (12.9–14.3, 14.0–15.4, 13.7–14.8 g kg^{-1} for grass, shrub, and forest, respectively) was lower than that on the sunny slope (14.8–15.3, 15.4–16.5, 14.2–15.1 g kg^{-1} for grass, shrub, and forest, respectively). Under different vegetation covers SIC increased in the top 0–50 cm of soil and kept a stable value in the 50–200 cm layer. For the entire profile the order of the SIC was for the sunny slope shrub> grass> forest and for the shady slope shrub≥ forest> grass (Wei Zhao *et al.,* 2016).

Alireza Raheb *et al.* (2017) showed that soil inorganic carbon content in the upper soil horizon of the arid region was higher than in the semi-arid region due to more leaching caused by higher humidity, stronger soil structure and the existence of *mollic*

epipedons. The highest SIC content (48%) was observed in the Cr horizon of pedon 11 in the semi-arid region. Although all pedons in this region contained thick calcic horizons, SIC content did not sharply increase by depth. The average SIC content increased according to the MAP of each region: dry sub-humid (15.84 %)> semi-arid (11.96 %)> arid (8.99 %).

Dar *et al.* (2017) reported that the calcium carbonate content in pear orchard surface soil (0–25 cm) at high, mid and low altitudes of Kashmir were found 6.4, 9.8 and 7.9 per cent in surface soil, respectively. In subsurface it was 7.0, 10.2 and 8.39 per cent, respectively in high, mid and low altitudes. Higher content in mid altitude soils might be due to calcareous nature of parent material. In general, the contents of calcium carbonate increased with depth, which could be due to leaching of bases from surface to subsurface layers.

SIC in soil samples collected at 0–20, 20–40, 40–60, 60–80 and 80–100 cm from 24 profiles in North China Plain revealed a general increasing trend of SIC content with depth was seen in the soil profiles, and the range of SIC also increased from 6 to 10 g C kg^{-1} in the 0–20 cm to 6–22.5 g C kg^{-1} in the 80–100 cm. Statistical analyses indicated that there was significantly vertical variation in SIC (Shi *et al.,* 2017).

Xiaoyang Han *et al.* (2018) studied changes in soil inorganic carbon stocks in deep profiles across the Loess Plateau of China and reported that the SIC contents first slightly increased and then decreased with depth, with the maximum values generally occurred at 60–100 cm. The differences in SIC contents among the four land use types were not significant in most of the layers. The mean SIC contents in the 0–300 cm profiles of grassland, cropland, woodland and shrubland were 15.66, 15.99, 16.82 and 17.22 g kg^{-1}, respectively. The woodland sites had higher SIC contents than other land use types in the 100–300 cm soil layer. The differences of SIC contents among the seven sites in each land use type were evident in grassland, woodland and shrubland stands, especially in the deep layers of the grassland stands and the upper layers of the shrubland stands.

2.3.3 Total carbon

Tan *et al.* (2007) reported that C concentrations of light fraction in all aggregate classes were significantly higher under no tillage (NT) and forest than under conservation tillage (CT). C concentrations in heavy fraction averaged 20, 10, and 8 g kg^{-1} under forest, NT, and CT, respectively. Of the total SOC pool, heavy fraction C accounted for 76% in CT soils and 63% in forest and NT soils. These data suggest that there is a greater protection of SOC by aggregates in the light fraction of minimally disturbed soils than that of disturbed soil, and the SOC loss following conversion from forest to agriculture is attributed to reduction in C concentrations in both heavy and light fractions.

Ranjith *et al.* (2008) showed that total carbon concentrations (TC) in the surface soil were significantly higher for grass buffer, agroforestry buffer and grass waterways (GWW) treatments compared with RC. The TC content for the row crop (RC) treatment was less than 2% whereas it was greater than 2.25% for the other three treatments. The GWW treatment had the highest TC among the four treatments. However, the difference was not significant among the permanent vegetative practices.

Shaoshan An *et al.* (2010) showed that compared to the bare fallow soil, the organic carbon (C_{org}) content was quite different between different forest plant communities. The highest content of C_{org} is about 25 g kg^{-1} which corresponds to typical grass communities in forest areas. There are clear differences between different communities. The C_{org} content in the abandoned cropland decreased approximately to 13 g kg^{-1}. Because of the abandonment for 14 years, the C_{org} content is not extremely low after only 5 years of cropping. Compared to the soil under forest and the abandoned cropped soil, the content of bare fallow soil was very low, with about 8 g kg^{-1} in the surface layer. This was possibly caused by heavy soil erosion during the rainy seasons. This explains that the vegetation cover conserves the C_{org} effectively.

Pinno and Wilson (2014) observed that ecosystem total C was significantly greater in forest (125.3 mg C ha^{-1}) than in either shrubland (92.4 mg C ha^{-1}) or grassland (80.7 mg C ha^{-1}), mainly due to greater aboveground biomass, coarse root biomass and the presence of a humus layer.

Venkanna *et al.* (2014) reported that among the different land-use systems, total C stock was highest in forest soils followed by fodder system, paddy, maize, cotton, redgram, intercrop, chilli, permanent fallow and lowest in castor system. The percentage contribution of organic to total carbon stock is highest under forest system (90%) followed by castor, paddy, chilli, permanent fallow, fodder, maize, red gram, intercrop and lowest in case of cotton system. Among different soil orders, *Vertisols* and associated soils contained greater total C stocks, followed by *Inceptisols* < *Alfisols*.

Among the different land uses, the TOC stock at surface soil in descending order was guava (28.8 Mg C ha^{-1}) > jamun (27.3 Mg C ha^{-1}) > litchi (25.7 Mg C ha^{-1}) > mango (19.2 Mg C ha^{-1}). All the land uses significantly differed from each other with respect to TOC stock. In all the land uses, different pools of SOC significantly decreased with depth increment. In mango plantation, very labile (VL) pool constituted 52% of the TOC at 0–20 cm depth, while labile (L), less labile (LL) and non labile (NL) pools constituted about 24, 10 and 14%, respectively. Guava stored highest amount of TOC (61 Mg C ha^{-1}) followed by litchi (46 Mg C ha^{-1}), jamun (43 Mg C ha^{-1}) and mango (40 Mg C ha^{-1}). All the land uses differed significantly from each other with respect to pools of SOC and TOC (Ashim Datta *et al.,* 2015).

Shehnaz Sharma *et al.* (2015) showed that total carbon was increased significantly with increase in number of poplar cutting cycles and an increase of 82.7 and 60.6%, respectively was found in poplar with four cutting cycles over one cutting cycles at 0–15 and 15–30 cm soil layers, respectively. The increase in total carbon stock with age of poplar plantation might be due to increased quantity of plant residues and reduced soil disturbances. The leaf litter added by poplar plantations also acts as mulch, cooling soil surface and thus reducing soil C oxidation.

Ashoka (2016) reported that at 0–15 cm depth of soil, significantly lower total carbon was noticed with 10 t of FYM ha^{-1} (14.34 g kg^{-1}) over maize residue at 5 t ha^{-1} (20.84 g kg^{-1}). Finger millet grown in mono cropping had significantly higher total carbon (19.74 g kg^{-1}) than legume rotation (15.44 g kg^{-1}). Total carbon was significantly higher in 100 per cent recommended dose of fertilizer (21.95 g kg^{-1}) whereas only

organic matter source has recorded the significantly lower value (14.34 g kg^{-1}). Content of total carbon decreased in soil with depth.

Chunli Li *et al.* (2016) reported that land-use changed the ratio of SOC/SIC without affecting the net soil total C accumulation in this area. The natural alpine grassland had the highest SOC (96.0 Mg C ha^{-1}) and lowest SIC (19.8 Mg C ha^{-1}) stocks, while the farmland had the opposite result, with the average of SOC and SIC stocks was 65.0 and 57.7 Mg C ha^{-1}, respectively. After 10-year restoration, SOC stock increased to 73.2 Mg C ha^{-1}, while SIC decreased to 47.8 Mg C ha^{-1} in the restored grassland.

Total carbon irrespective of depth was significantly higher in treatment 100 % NPK + FYM + lime (5135 mg kg^{-1}) followed by 100 % NPK + FYM (5023 mg kg^{-1}. Among different depths 0 to 15 cm recorded higher total carbon (6121 mg kg^{-1}) as compared to deeper layers (Gangamrutha, 2016).

The mean content of soil total carbon (STC) storage in the dry sub-humid region (11.32 kg m^{-2}) was higher than that of the semi-arid (6.28 kg m^{-2}) and arid (3.75 kg m^{-2}) regions. Furthermore, more than 50% of STC storage in the studied regions occurred in the deep soils (>60 cm) (Alireza Raheb *et al.,* 2017).

2.3.4 Labile/Active carbon

Fractionation of SOC, based on its susceptibility to oxidation with $KMnO_4$ solutions of various concentrations (33-333 m*M*), was introduced by Loginow *et al.* (1987) on the basis that microbiological decomposition of organic matter in the soil is also largely associated with an oxidation process of enzymatic character. Soil labile organic C as the most active fraction of soil organic C can be readily influenced by disturbance and management (Harison *et al.,* 1993). Blair *et al.* (1995) modified the procedure using a single concentration of $KMnO_4$ (333 m*M*) as the oxidizing agent.

The labile organic C pool in the literature refers to a readily metabolized soil organic matter component. The biologically active carbon pool is considered to be a key to soil productivity and a major soil nutrient reservoir (Wander *et al.,* 1994).

Decomposition of SOM is characterized by gradual changes in C functional groups. Mineralization of important inorganic nutrient elements also occurs as SOM decomposes. Considerable work has been done in characterizing and classifying different fractions of SOM in soils because, understanding the dynamics of soil organic carbon is important in the characterization of soil quality and terrestrial ecosystems.

At Raipur, under rice–wheat cropping system, the active soil organic carbon pools showed highest values in surface soil layer as compared to subsurface depths. Also, balanced application of only NPK fertilizers and FYM with NPK has enhanced the active pools (Singh *et al.,* 2003).

Among the fractions, the labile C fraction is decomposed relatively easily, has a greater turnover rate and a smaller in amount compared with recalcitrant fractions (McLauchlan and Hobbie, 2004). Labile C fractions fuel the soil food web and greatly influence nutrient cycles and many biologically related soil properties (Weil *et al.,* 2003).

Changming Yang *et al.* (2005) revealed that average content of easily oxidizable organic carbon (EOC) was 25–30% higher in the treatments that received chemical fertilizers along with organic materials than that observed under chemical fertilizer treatment. The EOC in paddy soils under the water regime of continuous waterlogging decreased by 21.7% for the chemical fertilizers+ FYM treatment and 30.6% for the chemical fertilizers + wheat straw treatment as compared to the water regime of alternative wetting and drying.

Shreshta *et al.* (2006) observed a large difference in $KMnO_4$ oxidizable soil organic C due to the effect of cultivation length and cropping system. During a 3–year study period large changes in soil C were observed for $KMnO_4$ oxidizable C but not for total carbon, indicating the usefulness of the $KMnO_4$ oxidized fraction for detecting a relatively short-term increase or decrease in soil C pool.

Purakayastha *et al.* (2008) reported that application of graded doses of NPK from 50% (130 kg N, 35 kg P and 41.5 kg K ha^{-1}) to 150% (390 kg N, 105 kg P and 124 kg K ha^{-1}) in the cropping system significantly enhanced $KMnO_4$ oxidizable C ($KMnO_4$–C)

fractions in soil. The increase in $KMnO_4$ oxidizable C fractions was greater (10.05 Mg C ha^{-1} in 1994 and 11.2 Mg C ha^{-1} in 2003) in 0–45 cm soil depth when farmyard manure (FYM) was applied conjointly with 100% NPK (260 kg N, 70 kg P and 83 kg K ha^{-1}).

Verma *et al.* (2011) opined that $KMnO_4$–C was significantly affected by nitrogen sources. On an average, all the nitrogen sources at different levels of substitution maintained higher amount of $KMnO_4$–C than the control. With increase in moisture content from field capacity to 2.5 cm standing water, $KMnO_4$–C decreased from 3.59 to 2.48 mg g^{-1}.

Benbi *et al.* (2012) showed that soils under agroforestry had significantly higher concentration of very labile C than the rice-wheat soils. Seventy-five percent of the soils under agroforestry had very labile C ranging between 2.1 and 4.2 g kg^{-1} as opposed to 0.3–1.9 g kg^{-1} under rice-wheat rotation. The concentration of labile C was significantly higher in soils under maize-wheat than rice-wheat system whereas agroforestry and rice-wheat systems were at par. The three agroecosystems did not differ in the concentration of less labile C. The highest concentrations of recalcitrant C occurred in soils under rice-wheat cropping. The labile C constituted about 60% of total OC in soils under agroforestry compared to about 37% in soils under rice-wheat cropping. The share of labile C in total OC was about 56% in maize-wheat system. The proportion of less labile C fraction ranged between 20 and 26% in the three agroecosystems. Soils under rice-wheat contained the largest proportion of C in the recalcitrant form (40%) compared to 18–21% in soils of the other two agroecosystems.

Kalambukattu *et al.* (2013) reported that in summer, labile carbon ranged from 1.8 g kg^{-1} in barren land to 12.9 g kg^{-1} in undisturbed forest and during winter season, the highest average LC content was found in the undisturbed forest (12.7 g kg^{-1} soil), while barren land showed the lowest value (1.7 g kg^{-1} soil).

Steve *et al.* (2013) concluded that the measured labile soil organic matter indicators (permanganate oxidizable carbon, C mineralization and N mineralization) were able to reflect both short– and long–term dynamics in corn–based cropping systems in the

upper Midwest. Overall, permanganate oxidizable carbon was the most sensitive indicator of both management and crop rotational diversity and C and N mineralization were more sensitive to treatment differences than inorganic N. Their results suggested that permanganate oxidizable carbon and C mineralization are differentially influenced by inputs, as permanganate oxidizable carbon was more influenced by stabilized C inputs and C-mineralization by greater substrate diversity from crop rotations.

Among banana, citrus and native forest systems labile fraction of the soil organic matter ranged from 1.37 (banana) to 4.32 g kg^{-1} (Native forest). In the native forest soil, the contents of labile fraction in the top soil and in the 10–30 cm depth were 58 and 29%, respectively, greater than in the cultivated soil. More labile fraction under native forest with larger, longer living roots than under cropland is probably related to the root-derived products. There was a decrease in labile fraction concentration with depth in the order forest > citrus > banana (Danielle *et al.,* 2014).

The amount of oxidizable organic C significantly varied among the horticultural land uses studied. On average, its amount was highest with guava (25.9 Mg C ha^{-1}) followed by jamun (25.1 Mg C ha^{-1}) = litchi (25.0 Mg C ha^{-1}) > mango (16.5 Mg C ha^{-1}) at 0-20 cm depth of soil, respectively. The highest decrease in magnitude of oxidizable organic C was in jamun (74%) followed by litchi (62%) > guava (46%) > mango (44%), respectively from 0–20 to 20–40 cm soil depth, respectively (Ashim Datta *et al.,* 2015).

Shehnaz Sharma *et al.* (2015) revealed that soils under higher number of poplar cutting cycles had higher stock of very labile carbon (VLC) in 0–15 cm soil layer but significant increase occurred only in poplar with four cutting cycles and rice-wheat (T_{RW}) system over poplar with one cutting cycle. Highest stock of labile carbon (LC) was recorded in T_{RW} (6.21 Mg ha^{-1}) and the increase was significant as compared to other treatments (0–15 cm). The LC stock decreased with increase in depth.

Sun Caili *et al.* (2016) showed that along the soil profile, very labile C contents were highly variable in the natural grassland and shrubland (*Caragana microphylla*), labile C and non-labile C contents were highly variable in the natural grassland and two

terraced croplands, respectively, and less labile C contents varied little. Among the land-use types, natural grassland had the highest very labile, labile C contents in the 0–0.4 m layers, followed by shrubland in the 0–0.1 m layer. Natural grassland had the highest non-labile C contents in the 1.0–4.5 m layers.

Moharana *et al*. (2017) reported that the magnitude of different fractions of oxidizable organic C *viz*., very labile C (VLC), labile C (LC), less labile C (LLC) and non-labile C (NLC) under a gradient of oxidizing conditions was followed in order: NLC > LLC > LC > VLC in all the systems except barley-fallow, mustard-moth bean and chickpea-groundnut. In wheat–pearl millet systems, VLC fraction constituted 17% of the TOC while LC, LLC and NLC fractions constituted 22%, 23% and 38%, respectively.

The range for Labile C (LC) concentration in the 0–5 cm soil depth was 418 to 1626 mg C kg^{-1} at Takarla and 807 to 1963 mg C kg^{-1} at Mukerian site (Punjab). In Takarla, its concentration was higher in agro-forestry (1626 mg C kg^{-1}), followed by forestry (755 mg C kg^{-1}), grassland (705 mg C kg^{-1}) and cropland (418 mg C kg^{-1}). At Mukerian, grassland possessed significantly higher value (1963 mg C kg^{-1}) followed by forestry (1540 mg C kg^{-1}), cropland (1420 mg C kg^{-1}) and agro-forestry (806.66 mg C kg^{-1}) (Rajwinder Kaur *et al.,* 2018).

2.3.5 Water soluble carbon

Water soluble carbon is much more sensitive to soil management than SOM as a whole and can be used as a key indicator of soil natural functions. Despite the fact that labile C accounts for a small portion of the total organic matter in the soils, WSC is the most mobile and important carbon source for microorganisms and is an alternative tool for monitoring adverse impacts of management on soil quality. The water soluble carbon is the main energy source for soil microorganisms, a primary source of mineralizable N, P, and S and it influences the availability of metal ions in soils by forming soluble complexes (Stevenson, 1994). Concentrations of water-soluble and bio–available SOC have been reported to be high in agricultural soils (Boyer and Groffiman, 1996).

The term water soluble organic carbon is defined as the entire pool of water–soluble organic carbon either sorbed on soil or sediment particles or dissolved in interstitial pore water (Tao and Lin, 2000). Hot water–soluble carbon represents easily degradable fraction of carbon and has been suggested as a stability indicator of soil organic matter (Schulz *et al.,* 2003).

Manna *et al.* (2005) reported that water soluble organic carbon increased significantly with application of NPK + FYM as compared to NPK alone. Similar results were also reported by Manna *et al.* (2007). They advocated that use of FYM/lime with 100 per cent NPK is mandatory for enhancing crop productivity and maintaining soil health. Dou *et al*. (2007) reported that the depth distribution of soil organic carbon, dissolved organic carbon, and total N indicated the treatment effects below the maximum tillage depth (25 cm) under tillage systems, suggesting that roots or translocation of dissolved organic matter from surface soils, contributed to higher soil organic matter levels in subsurface soils.

The three agroecosystems (Agroforestry, Maize–wheat and Rice–wheat) did not exhibit significantly different concentration of water–soluble carbon, though the values were higher in agroforestry and maize–wheat systems than rice–wheat system. Soils in rice-wheat system had significantly lower concentration of hot water-soluble C than the other two agroecosystems (Benbi *et al.,* 2012).

The influence of land use change on soil carbon pools, mineralization and fluxes in *Vertisols* of Central India, were demonstrated by Pramod *et al.* (2012). The water soluble carbon (WSC) and microbial biomass carbon (MBC) were reported to be higher under forest (101.6 µg g^{-1}, 430.7 µg g^{-1}) followed by horticultural (70.6 µg g^{-1}, 355.5 µg g^{-1}) and agricultural field (13.8–36.1 µg g^{-1}, 88.9–257.8 µg g^{-1}). The higher MBC under the forest and horticulture systems indicated that these sites received higher quantity of litter fall (substrate) for microbial decomposition every year.

Geetha Kumari *et al.* (2013) revealed that there was significant build up of water soluble carbon due to 100 per cent NPK alone or in combination with lime/FYM in

Alfisols under maize-wheat cropping systems. The water soluble carbon in 100 per cent NPK treatment was found significantly higher (33.3 mg kg^{-1}) over treatment receiving 100 per cent N (20.3 mg ha^{-1}), whereas it was on par with 100 per cent NP. This indicated that imbalanced fertilizer gave adverse effect on water soluble carbon. The highest water soluble carbon (52.2 mg ha^{-1}) was recorded in 100 per cent FYM treated soil which was significantly higher with 100 % NPK + lime.

Water soluble organic carbon (WSOC), an active pool of soil organic matter, varied from 36.2 mg kg^{-1} in control to 57.2 mg kg^{-1} in the soil receiving poultry manure as amendment along with chemical fertilizers for NPK (Khursheed *et al.,* 2013).

Irrespective of soil depths, NP+FYM invariably showed higher content of water soluble carbon over all other treatments. The control and N treatments showed lower content of water soluble carbon. The water soluble carbon concentrations in 0 to 20 cm, 20 to 40 cm and 40 to 60 cm depths were observed highest for NP + FYM followed by NP + S and FYM, and both of them were significantly higher than NP. However, in the deeper layers (60 to 80 cm and 80 to 100 cm), the difference in water soluble carbon among the treatments was not significant (Liu *et al*., 2013).

Manna *et al.* (2013) observed that water soluble carbon was significantly higher with application of NPK + FYM as compared to inorganic fertilizer treatment. On an average, water soluble carbon accounted for 0.27 to 0.69 per cent of the total organic carbon in the top surface layer (0 to 15 cm) and the trend in the deeper layer were similar to those in the surface layer.

Shehnaz Sharma *et al.* (2015) revealed that hot water soluble carbon increased with increase in cutting cycles both in 0–15 and 15–30 cm soil layers but in rice-wheat system, unlike all other carbon pools. In the 30–45 cm soil depth, rice-wheat registered the highest magnitude of decrease from the surface as compared to all other treatments.

Water soluble organic carbon was higher in treatment 100 % NPK + FYM + Lime (26.2 and 27.6 mg kg^{-1}) followed by 100 % NPK + FYM (25.3 and 26.6 mg kg^{-1}) irrespective of depth during 2013 and 2014, respectively (Gangamrutha, 2016).

Rajwinder Kaur *et al.* (2018) reported that hot water soluble C was highest (490 mg kg^{-1}) in agro-forestry, followed by grassland (240 mg kg^{-1}), forestry (150 mg kg^{-1}) and cropland (130.0 mg kg^{-1}) at Takarla village (Punjab). Among all land uses, only agroforestry possessed significantly higher value than others. The loss of organic carbon with cultivation could be attributed to the repeated exposure and subsequent aeration and oxidation of light fraction of organic carbon associated with macroaggregates and macro-pores.

2.3.6 Microbial biomass carbon

Microbial biomass carbon (MBC) is part of the active pool of soil organic matter, driving force of nutrient turnover and early indicator of soil/crop management that responds very quickly to changes in crop management practices. The microbial biomass generally comprises approximately two per cent of the total organic matter in soil. It plays a critical role in regulating the C and N cycling processes in the soil.

The microbial biomass is an essential component of organic matter so also its turnover (Jenkinson, 1988). Under tropical conditions, continuous application of fertilizer and organic manures in balanced quantities increased the soil microbial biomass C and N. Similar to light fraction organic carbon, microbial biomass too is known to respond rapidly to any changes in organic inputs than the SOM itself (Powlson *et al.,* 1987).

Studies have shown that microbial biomass responded quickly to change in soil perturbation by tillage (Carter, 1986) and soil moisture (Skopp *et al.,* 1990). Brookes (1995) agreed on the use of microbial biomass C as indicator of soil quality, owing to its high sensitivity to changes in land use and management practices. Application of mineral N fertilizers and manures has been reported to significantly influence the build-up and dynamics of soil microbial biomass (Mahmood *et al.,* 1997).

Kaur *et al.* (2000) reported that microbial biomass carbon was low in rice-berseem crops (96.14 mg g^{-1} soil) and increased in soils under tree plantations (109.12–143.40 mg g^{-1} soil) and agri–silvicultural systems (133.80–153.40 mg g^{-1} soil). Microbial biomass was higher by 42% (microbial C) and 13% (microbial N) in tree-based systems

as compared to monocropping. Microbial biomass immobilized 2.32–2.57% of the soil carbon and 4.08–4.48% of the soil nitrogen in tree-based systems. Soil carbon increased by 11–52% due to integration of trees along with the crops for 6–7 years.

The soil microbial biomass serves as a sink (immobilization) and a source (mineralization) of important nutrient elements, controlling the supply of nutrients to crops through mineralization and immobilization processes (Abbasi *et al.,* 2001). Microbial biomass, which is a relatively small component of soil organic matter, plays an important role in nutrient cycling and organic matter stabilization in soils (Jedidi *et al.,* 2004).

Zou *et al.* (2005) observed that soil microbial biomass carbon levels were highest in the *Alfisol* (2.5 mg g^{-1}) and its organic layer (4.2 mg g^{-1}) materials from the evergreen-broadleaved forest, and lowest in the *Entisol* with a value of 0.20 mg g^{-1} of soil.

Rudrappa *et al.* (2006) noticed that microbial biomass C content was greater in 100 per cent NPK + FYM over other treatments particularly at 0 to 15 and 15 to 30 cm soil depths. At 0 to 15 cm, both 100 and 150 per cent NPK showed significantly higher MBC over 50 per cent NPK treatment and there was an improvement in MBC content in 100 per cent NPK over either 100 per cent NP or 100 per cent N, particularly at 0 to 15 cm depth. At 15 to 30 cm, MBC in 150 per cent NPK was higher over 50 per cent NPK. Irrespective of soil depths, 100% NPK + FYM invariably showed higher content of MBC over all other treatments. The control plot showed lowest content of MBC.

Kara and Bolat (2008) in a study reported that the mean values for microbial biomass C were 1028.29 µg g^{-1}, 898.47 µg g^{-1} and 485.10 µg g^{-1} in the forest, pasture and agricultural soils, respectively. Liao and Boutton (2008) signified that changes in microbial C under tree based cropping system could be influenced by possible microclimatic modifications induced by plant cover, such as increases in soil moisture due to reduced evaporation or hydraulic redistribution and reductions in soil temperature due to increased shading as well as litter fall.

Rekha *et al.* (2010) reported that microbial biomass carbon varied from 91.75 to 239.44 µg C g^{-1} soil across soil depths. Legumes are one of the important components to increase microbial biomass in soils (Siddique *et al.,* 2008; Deakin and Broughton 2009).

The microbial biomass carbon values were affected by soil types and increased by organic matter applications, ranging from 200 to 1,168 mg C/kg. The microbial biomass carbon values in brown lowland soils were higher than those in gray lowland soils. In contrast, the values of microbial biomass nitrogen did not show any appreciable difference among the soil types. The microbial biomass carbon and microbial biomass nitrogen values corresponded to 1.1–5.8 and 1.7–5.1%, respectively of the soil organic matter. Similar tendencies were also observed in the farmers' fields. The average values of soil carbon stocks for the depth of 0–30 cm in lowland soil groups ranged from 47 to 63 Mg C/ha (Fujiyoshi Shibahara *et al.,* 2010). Leguminous crops are effective in improving soil fertility, differential accumulation of organic carbon, nitrogen and inorganic nutrients in topsoil under intercropping systems as well as accumulation of inorganic nutrients tend to increase soil microbial activities there by increasing the microbial carbon. These results are in consonance with the findings of (Singh *et al*., 2010).

Intercropping systems maintained a positive and significant correlation with abiotic variables *i.e.* soil moisture, soil temperature, rainfall, mean air temperature and relative humidity thereby favouring suitable environment for the growth and activity of micro flora, macro fauna and microbial biomass C and N as reported by Srinivasan *et al.* (2010). Amrita Chakraborty *et al.* (2011) found that the MBC was highest in the 100 per cent NPK + FYM treatment (431 µg g^{-1}) but was statistically similar to 150 per cent NPK treatment (392 µg g^{-1}). The MBC in the 100 per cent NPK treated soil (364 µg g^{-1}) was slightly lower than the 150 per cent NPK treatment. Among the exclusive mineral fertilizer treatments, 100 per cent N treatment recorded the lowest MBC (306 µg g^{-1}).

Distinct difference of MBC content was observed among different treatments and at different depths in a long term rice-wheat system. Continuous application of FYM along with NPK resulted in a significantly higher soil MBC compared to NPK at all four

locations (Ludhiana, Sabour, Kalyani and Kanpur). The MBC content of plots which received crop residue along with NPK was at par with NPK + FYM at all places except Ludhiana. However, the MBC content of surface soil in NPK + green manure treatments was significantly lower than NPK + FYM at Ludhiana, Sabour and Kalyani except Kanpur where it was at par. The MBC content of surface soil in NPK + green manure plots was at par with NPK + crop residue at all places except at Kalyani where it was significantly lower (Nayaka *et al.,* 2012).

Park *et al.* (2012) showed that the mean microbial biomass C concentration up to 30 cm depth was 510 mg C g^{-1} soil in the *P. rigida* plantation and 764 mg C g^{-1} soil in *the L. kaempferi* plantation. The microbial biomass C concentration in the *P. rigida* and *L. kaempferi* plantations was 477 and 300 mg C g^{-1} soil at 0–10 cm, 224 and 126 mg C g^{-1} soil at 10–20 cm and 64 and 84 mg C g^{-1} soil at 20–30 cm depths.

G_0 (pure tea system) had the lowest soil microbial biomass C (C_{mic}) in comparison with G_1 (intercropped with grafted ginkgo seedlings at a spacing of 10 m × 10 m) and G_2 (int intercropped with grafted ginkgo seedlings at a spacing of 6 m × 8 m) in both upper and middle layers, and there were no significant differences between G_1 and G_2 in the two layers. Meanwhile, in lower layer, soil microbial biomass C was significantly higher in G_2 than in G_0 (Yaling Tian *et al.,* 2012).

Geetha Kumari *et al.* (2013) noticed that application of FYM alone or in combination with chemical fertilizers significantly increased the soil microbial biomass carbon as compared to application of only inorganic fertilizers. They also reported that the microbial biomass nitrogen followed a trend similar to that of microbial biomass carbon.

Peiyu Luo *et al.* (2015) observed that the SMBC content ranged from 77.5 mg kg^{-1} in control to 203.2 mg kg^{-1} in the manure + NPK plots. Except for the N treatment, SMBC contents of all fertilized treatments were significantly higher than the control treatment. These results indicated that long-term deficiency of P significantly affected microbial biomass in soil as compared to plots receiving sufficient P.

Tara Bahadur Ghimire and Om Prakash Singh Bana (2015) reported that soil microbial biomass carbon (SMBC) was significantly influenced by tree density and fertility levels under poplar + Indian mustard inter cropping system in both the years. SMBC increased with high tree densities having maximum (239.0 µg g^{-1} soil), higher SMBC under highest (*i.e.* 1000 trees/ha) density both in 2008–09 and 2009-10, respectively, comparing other densities including sole crop in first year and sole crop and 250 trees/ha density in second year. The differences between 250 and 500 trees/ha and 500 and 1000 trees/ha densities were not significant in 2009-10. Among the fertility levels, the maximum 227.88 µg g^{-1} soil was significantly higher in 75% of recommended NPK, respectively, compared to 100 and 125% of recommended NPK both in 2008–09 and 2009–10. The differences between 50 and 75% and 100 and 125 % of recommended NPK were not significant in both the years.

Gangamrutha (2016) revealed that irrespective of depth microbial biomass carbon was significantly higher in 100 % NPK + FYM + Lime (203.0 and 205.8 mg kg^{-1}) followed by 100 % NPK + FYM (198.3 and 200.5 mg kg^{-1}) during 2013 and 2014, respectively in a long term fertilizer experiment at GKVK, Bangalore. Among different depths significantly higher MBC (228.8 and 231.6 mg kg^{-1} during 2013 and 2014 respectively) was recorded at 0 to 15 cm layer as compared to deeper layers.

Ramulu *et al.* (2017) reported that the SMB of carbon (µg g^{-1} soil) ranged from 215.9 under custard apple to 314.6 under field bean in 2012; and 217.5 under custard apple to 311.8 under custard apple + cowpea in 2013 with mean of 257.7 and 257.3 in the two years, respectively. The increase in SMB of carbon was due to an increase in the soil organic matter under intercropping systems and the reduced rate of leaching in the soil profile. Higher organic carbon was mainly contributed by the decomposition of leaf litter, root and crop residues coupled with lower loss of soil carbon.

Soil samples collected from four different locations of Meerut and Bulandshare districts (U.P) under rice-wheat cropping sequence revealed that the microbial biomass carbon in surface (0–15 cm) and sub surface soil (15–30 & 30–45 cm) varied from 280 to 298, 150 to 172 and 77 to 90 µg g^{-1} soil with an average value of 288.25, 160.50 and

81.50 µg g^{-1} soil, respectively. The mean value microbial biomass carbon for 0–45 cm depth varied from 153.00 to 178.33 µg g^{-1} soil (Ravindra Kumar *et al.,* 2017).

Microbial biomass carbon was reported higher (430.7 µg g^{-1}) under forest land use system followed by organic farming (230.0 µg g^{-1}) land use system while both these system are significantly higher in MBC as compared to agricultural and riverine land.). Agricultural soil has 50- 75% less C stocks compare to reference site which is under native forest. Light fraction carbon (LFC) comprised largely of incompletely decomposed organic residues, may provide a sensitive indicator of the effects of cropping practices on soil organic matter (Usha Kaushik *et al.,* 2018).

MBC was significantly affected by both management practice and sampling time. MBC was increased by 31.7%, 25.1% and 30.5% under integrated agricultural practice (IP) compared with conventional practice (CP) in June, August and October, respectively. MBN was significantly affected by sampling time. The lowest MBC and MBN values were observed in October. Moreover, the ratio of MBC to MBN was also affected by sampling time. The highest MBC–MBN ratio was found under CP in August, and the lowest ratio was observed under CP in October (Luying Sun *et al.,* 2018).

2.4 Effect of agri–horticulture systems on nitrogen dynamics in soil

2.4.1 Available nitrogen

Available N in the soil of the alley crops was on average 4.23 µg N g^{-1} soil higher that sole crop under tropical agroforestry and annual cropping systems. The average concentration of nitrate plus ammonium (available N) in the soil over the whole season was 2.68 µg N g^{-1} of soil higher under the alley crops than the sole crop (Haggar *et al.,* 1993).

Carpenter–Boggs *et al.* (2000) opined that inclusion of a legume, particularly alfalfa, in the rotation increased net N mineralized. Generally, more net N was mineralized from plots receiving no fertilizer N than from soil with a history of N fertilization. Rotation and N fertilization significantly affected net N mineralization in soil samples. Fertilizer addition may increase microbial activity temporarily, either

directly after fertilization causing a priming of soil organic matter mineralization, or indirectly when large quantities of lower C/ N ratio residues are incorporated into well-fertilized soils, leaving less mineralizable material for future use.

The nitrogen content increased by 8–46% (0–7.5 cm soil depth) due to integration of trees with crops; the increase being maximum in the case of *Acacia* based systems. Averaged across the distance from the trees at 0-7.5 cm soil depth, carbon and nitrogen concentrations were found to be higher in the case of *Acacia* based systems (0.57–0.63% C; 0.068–0.077% N) and *Populus* based systems (0.41–0.59% C; 0.047–0.073% N) as compared to *Eucalyptus* based systems (0.38–0.54% C; 0.039–0.054% N). It is evident that the ameliorative effect of trees was more conspicuous at 1 and 2 m distance from trees and in upper soil layers (0–7.5 cm soil depth) (Kaur *et al.,* 2000).

The contents of total, available, ammoniacal and nitrate forms of nitrogen in the soil profiles of Tarai soils of West Bengal decreased with depth. Available N content in the surface soils ranged from 52 to 220 mg kg^{-1} and accounted for 0.087 per cent of total N. Again, mineral N (NH_4–N + NO_3–N) of the surface soils contributed 53.3 to 83.6 per cent of available N and rest was associated with the organic fractions. The status of nitrate nitrogen in these soils was low (ranged from 3.1 to 11.9 mg kg^{-1} in the surface soils) possibly due to the leaching down under high rainfall and coarse texture. A relatively higher content of nitrate nitrogen in the surface horizon may be on the other hand due to high nitrification (Saha *et al.,* 2000).

The available N in soil after harvest of mustard crop under poplar + Indian mustard intercropping system was not influenced by tree density. The maximum (178.1 kg/ha) more soil available N was recorded with 75% as compared to 50 and 125% of recommended NPK. The differences between 50 and 100; 50 and 125 and 75 with 100% of recommended NPK were not substantial. The available N in soil decreased with increasing soil depths having the maximum (197.3 kg/ha) high soil available N at 0–15 cm depth in both years, comparing to 15–30 and 30–45 cm depths. At 15–30 cm depth higher available N compared to 30-45 cm depth occurred in both years. The maximum available N (kg/ha) was found in surface (0–15 cm) layer during both the years. The

lowest available N was recorded in the lower most soil of 30–45 cm (Tara Bahadur Ghimire and Om Prakash Singh Bana, 2015).

Murtaza Hussain Shah *et al.* (2017) studied that the application of different doses of organic manures and fertilizers significantly influenced the available N content of soil. In the surface soil (0–20 cm), the maximum available N (346.82 kg ha^{-1}) was recorded for the treatment supplied with 80 per cent of recommended doses of NPK + FYM + dalweed + biofertilizer (Rhizobium) followed by treatment supplied with 60 per cent of recommended doses of NPK + FYM + dalweed + biofertilizer (Rhizobium) (343.13 kg ha^{-1}).

Saswati Ghosh *et al.* (2017) reported that under guava based intercropping system, the guava + banana intercropping system significantly increased the maximum available nitrogen content of soil to 226.53, 212.03 and 181.91 kg ha^{-1} within 0–15, 15–30 and 30–45 cm, respectively. The effect of guava + banana intercropping system increased the available nitrogen content of soil might be due to greater recycling of bio-litters in the inter space with higher percentage of nitrogen as compared to other treatments.

Available soil nitrogen was significantly influenced by the agroforestry systems as compared to the soil cropping (devoid of trees). The status of N under agri–horticultural system, agri-silvi-horticultural system and sole cropping were recorded to be 132 kg/ha, 110 kg/ha and 144 kg/ha respectively, before sowing of the wheat crop which significantly reduced to 120 kg/ha, 104 kg/ha and 136 kg/ha respectively, under all the systems. this may be due to over utilization of the nutrients by the different components in the agroforestry system as returned to soil in the form of litter fall and its decomposition and also due to non-leguminous nature of all the components as a result of which there was no or a very less amount of atmospheric nitrogen fixation that further affect soil nutrient status (Vishal Johar *et al.,* 2017).

Available nitrogen in studied horticulture land use systems in Ganderbal district of Kashmir valley with the confidential interval ranged from 335.83 to 392.38 kg ha^{-}

[1]with a mean value of 364.10 kg ha^{-1}. All the profiles showed that the available nitrogen decreases with the increase in depth. The available N found to be maximum in surface horizons and decreased regularly with depth which is due to decreasing trend of organic carbon with depth and cultivation of crops are mainly confined to the surface horizon (Rhizosphere) only and at regular interval the depleted nitrogen content is supplemented by the external addition of fertilizers during crop cultivation (Khanday *et al.,* 2018).

2.4.2 Ammonical nitrogen

Pandey (2007) concluded that agroforestry trees play a central role in the build up of nutrient pools and their transformations and observed that concentration of NH_4–N was the highest during wet season (May-October) and the lowest during post-wet season (November-January) under coconut (*Cocos nucifera),* clove (*Eugenia caryophyllata*) and nutmeg (*Myristica fragrans*) tree species. On the contrary, concentration of NO_3–N was the lowest in the wet season and the highest during the post-wet season. The concentrations of the mineral N were the highest under the nutmeg and the lowest under the coconut trees. It was also reported that like the pool sizes, mean annual mineralization was the highest under the nutmeg (561 mg kg^{-1} yr^{-1}) and the lowest under the coconut trees (393 mg kg^{-1} yr^{-1}). No significant increase in mineral N pools with stand age of poplar was observed by Sartori *et al.* (2007) although there were increasing trends within the surface layer (0–15 cm). But in the sub-surface layers even these increasing trends diminished (30–50 cm).

Application of chemical fertilizers alone or in conjunction with organic manures increased the NH_4–N content of soil significantly over control. In 0–0.15 m depth it varied from 29.8 mg kg^{-1} in control to 57.8 mg kg^{-1} in plots where 50% NPK + 50% N through green manure was applied during *kharif* followed by 100% NPK during *rabi*. In subsurface layer, the ammonical–N content varied from 26.3 mg kg^{-1} in control plot to 54.3 mg kg^{-1} under 50% NPK + 50% N through green manure during *kharif* followed by 100% NPK in rabi (Swapana Sepehya, 2011).

Shehnaz Sharma *et al.* (2015) reported that under poplar based cropping system soil ammonical nitrogen (AN) improved with increase in number of cutting cycles of

poplar. It was the highest in four cutting cycles (24 years of poplar plantation) in 0–15 and 15–30 cm soil layers but in the 30–45 cm soil layer it was highest in rice–wheat sequence. The lowest content was observed in one cutting cycle (6 years of poplar plantation) under all soil depths. Lower content of AN in rice-wheat cropping system than four cutting cycles of poplar might be due to the higher uptake of AN by rice, because under submerged conditions AN is preferred for uptake.

Incorporation of 10 t FYM ha^{-1} recorded significantly higher ammonical nitrogen (30.24 mg kg^{-1}) than the maize residue at 5 t ha^{-1} (26.93 mg kg^{-1}) at 0–15 cm depth. Legume rotation system in finger millet recorded significantly higher ammonical nitrogen (29.16 mg kg^{-1}). Ammonical nitrogen after harvest of crop was significantly higher in organic matter + 100 per cent recommended dose of fertilizer (34.35 mg kg^{-1}) over the absolute control (24.08 mg kg^{-1}). The organic matter alone (27.53 mg kg^{-1}) was on par with organic matter + 50 per cent recommended dose of fertilizer (31.64 mg kg^{-1}). Lower soil depths recorded less ammonican nitrogen content compared to surface (Ashoka, 2016).

Gangamrutha (2016) conducted an experiment and reported that during 2013 significantly higher hydrolysable ammonical N among different treatments was recorded in 100 % NPK + FYM + Lime (103.7 mg kg^{-1}) followed by 100 % NPK + FYM (100.7 mg kg^{-1}) in a long term fertilizer experiment at GKVK, Bangalore. Similar trend was observed during 2014.

The ammonical N (AN) contents in the farmland and grassland of Tibet decreased with increasing soil depth at surface 0–20 cm. By contrast, the AN contents gradually increased from 20 cm and deeper, but these differences were not significant. The AN content in the 0–5 cm layer of the grassland was 7.42±4.61 mg/kg, which was then reduced by 41.64% to 4.33±3.19 mg/kg in the 10–20 cm layer. Furthermore, the AN content increased to 5.03±2.88 mg/kg in the 40–50 cm layer, thereby increasing 13.92% compared to the content of the 10–20 cm layer. The CV of AN along the vertical profile was 20.79% (Liu Heman *et al.,* 2016).

Purnananda *et al.* (2017) reported that in soils under coconut land use system exchangeable ammonical nitrogen fraction mean values varied from 15.56 to 14.33 ppm, respectively. Exchangeable ammonical nitrogen in soil under arecanut land use system recorded 11.82 to 11.87 ppm in surface and subsurface, respectively. Under pomegranate land use system it was 14.90 to 14.46 ppm in surface and subsurface, respectively. The exchangeable ammonical nitrogen showed a decreasing trend with depth due to low rate of mineralization in the subsurface soils.

Syed Shujat Hussain *et al.* (2017) reported that the soils of apple growing soils of Pulwama district of Kashmir Valley contained exchangeable NH_4–N content in soil at different depths varied from 5.0 to 25.5 mg kg^{-1}.The surface soils are richer with respect to exchangeable NH_4–N content than the sub-soils and constituting 1.75 to 12.6 per cent of total -N.

2.4.3 Nitrate nitrogen

Benbi *et al.* (1991) studied a long term fertilizer experiment with 16 cycles of cropping (maize-wheat-fodder cowpea) and reported that the application of fertilizer N without P and K or in combination with only P resulted in higher NO_3–N concentration in the soil profile than the application of N with P and K. With an annual application of 320 kg N ha^{-1} alone, a peak in NO_3–N accumulation occurred at 135 cm soil depth. However, with the application of NPK, no peak in NO_3–N distribution was discernible and its content at most of the sampling depths was either less than or equal to N and NP treatments. The annual application of 10 tons farm yard manure (FYM) per ha along with NPK resulted in a relatively lower NO_3–N content in the sub soil. The amount of NO_3–N accumulation in the soil profile decreased as the cumulative N uptake by the crops increased. Application of fertilizer amounts greater than that of the recommended (100% NPK) resulted in low percent N recoveries in crops and greater NO_3-N accumulation in the soil profile.

While studying the changes in the fractions of N, P and K of soil, Bhardwaj *et al*. (1994) observed that application of FYM along with 100% NPK increased amino sugar N, hydrolysable NH_4–N, amide N, amino acid N and acid insoluble N but inorganic

fractions of N like NH_4–N and NO_3–N decreased with combined use of manures and fertilizers.

The low cropping diversity (LOW) resulted in greater nitrate–N compared to diversified annual and perennials (DAP) in the 0–60 cm depth in 1995 and 1996, in the 0–30 cm depth in 1997, in the 15–90 cm depth in 1999 and in all the depths in 1998 and 2000. It also showed greater nitrate–N than the diversified annual grains (DAG) diversity in the 0–60 cm depth in 1995, 1996 and 1998, in all soil layers in 1999 and in the 0–30 cm depth in 2000. Among the DAG and DAP diversities, DAG had greater nitrate–N level than the DAP in six cases (0–15 cm in 1997, 30–60 cm in 1998 and 15–30 cm, 30–60 and 60–90 cm in 2000), while the opposite was true for two cases (0–15 cm in 1996 and 1999). For the 0–90 cm soil, LOW diversity had greater nitrate–N compared to both other diversities in all the six years (except DAG in 1997) and DAG showed greater nitrate–N than DAP in 1997, 1998, and 2000. These data showed that the effect of diversity on soil N was generally LOW>DAG>DAP (Malhi *et al.,* 2002).

Yang Hong-jun *et al.* (2007) reported that concentrations of the total nitrogen and NO_3–N in the topsoil are high. They decrease with depth and reach their minima in 60 cm. But in 80 cm, they ascend in a small degree; and over 80 cm, the concentrations retain relatively stable. The looser topsoil is a better aerobic environment with higher oxidation-reduction potential. The denitrification is restrained while the nitrification get strengthened, then results in the accumulation of NO_3–N.

In a study on luvisols under agroforestry and conventional systems in semi-arid zone of Brazil, Maia *et al.* (2008) reported that NO_3^-–N in both the depths (0–6 cm and 6–12 cm) where the highest content was observed in traditional agroforestry. This higher total and NO_3^-–N was because of more organic matter under agroforestry, which upon mineralization might have released more of NO_3^-–N as compared to other land uses.

Swapana Sepehya, (2011) revealed that the nitrate-N content of soil in 0–0.15 m depth differed significantly under different treatments. The range of variation was from 7.0 mg kg^{-1} under control and 24.5 mg kg^{-1} under the treatments where 50% N was

substituted through green manure during *kharif* followed by 100% NPK during *rabi*. Application of chemical fertilizers alone or in combination with organics in subsurface soil increased the nitrate-N content of soil, the differences however, were not significant.

Ashoka (2016) revealed that incorporation of 10 t FYM ha^{-1} recorded significantly higher nitrate nitrogen (19.43 mg kg^{-1}) than the maize residue at 5 t ha^{-1}(17.31 mg kg^{-1}) at 0–15 cm depth. Legume rotation system in finger millet recorded significantly higher nitrate nitrogen (19.29 mg kg^{-1}). Nitrate nitrogen after harvest of crop was significantly higher in organic matter + 100 per cent recommended dose of fertilizer (21.13 mg kg^{-1}) over 100 per cent recommended dose of fertilizer (16.56 mg kg^{-1}). The organic matter alone (17.81 mg kg^{-1}) was on par with organic matter + 50 per cent recommended dose of fertilizer (19.71 mg kg^{-1}).

Liu Heman *et al.* (2016) studied that the nitrate N (NN) concentration in both farmland and grassland of Tibet decreased with increasing soil depth. The NN contents in the 0–5 and 40–50 cm layers of the farmland were 28.56±27.23 and 5.90±5.97 mg/kg, respectively, corresponding to a reduction by 79.34%. This decline was much larger than that in the total nitrogen content. The coefficient of variation value of the NN content among layers was 70.47%. However, the difference in NN between the depths of 0–5 and 5–10 cm was not significant.

Xiukang Wang and Yingying Xing (2016) indicated that high contents of soil nitrate-N were mainly distributed at 0–20 cm at 31 days after sowing in 2012 and the soil nitrate-N concentration in the plastic film mulching with basal fertilizer and top dressing (MN_2) treatment was 1.58 times higher than that did not receive fertilizer. The MN_2 treatment greatly increased the soil nitrate–N content in the upper layer of soil (0-40 cm) and the mean soil nitrate–N content was increased nearly 50 mg kg^{-1} at 105 days after sowing compared with CK (no fertilizer without plastic film) treatment in 2012. The soil nitrate–N leaching amount in MN_1 (basal fertilizer with no top dressing) treatment was 28.61% and 39.14% lower than BN_1 (basal fertilizer with no top dressing and no mulching) treatment, and the mulch effect attained to 42.55% and 65.27% in MN_2 lower than BN_2 (basal fertilizer and top dressing with no mulching) in both years.

Soils under coconut land use system recorded nitrate nitrogen fractions mean values varied from 27.63 to 8.19 ppm in surface and sub–surface, respectively. While, under arecanut based land use system it was in the range of 21.00 to 6.78 ppm in surface and subsurface, respectively. Under pomegranate land use system it was 26.47 to 8.26 ppm in surface and sub-surface, respectively. Nitrate nitrogen content showed a zone of maximum concentration at the surface than the subsurface due to rapid mineralization of organic matter in surface layer compared to subsurface soils (Purnananda *et al.,* 2017).

Syed Shujat Hussain *et al.* (2017) reported that the NO_3–N content ranged from 6.2 to 18.7 mg kg^{-1} in the apple growing soils of Pulwama district of Kashmir Valley. The total nitrogen present range was 1.3 to15.2 per cent. These data indicate that the surface soil had relatively higher NO_3–N content as compared to the sub-surface. Soils showed a declining trend of NO_3–N with depth, which may be attributed to lower intensity of mineralization in the lower horizons. In another experiment author reported that legume treatments had significant amount of nitrate nitrogen which might be due to release of nitrogen fixed in nodules after harvest which upon mineralization increased the nitrate nitrogen content in soil. This may also be due to nitrification process wherein the ammonical nitrogen converted to nitrate nitrogen through action of microbes (Fabian Beeckman *et al.,* 2018).

2.4.4 Total nitrogen

Jha *et al.* (2000) studied the effect of agro-forestry (*Populus deltoide* + wheat) and wheat alone land uses on the soil properties in Yamunanagar (Haryana) and reported that total nitrogen content was higher in the soil under agro-forestry than wheat alone land use.

Sharma and Nepal Singh (2001) reported that higher total nitrogen content in oran lands was due to greater return of nitrogen through better vegetative cover and litter fall. Datta and Dhiman (2001) observed an increase of nitrogen content from 1.01 to 1.25 times more in *Gliricidia arborea*, *Michelia champaca* and *Albizzia lebbeck* when compared to control which was mainly due to leaf shading and root decay.

In a study on transformations of N as influenced by trees, Burman *et al.* (2002) reported that soil under the canopy of most trees had higher total N as compared to nearby cultivated fields. Tree species, however, differed in selective build up of different N fractions. *Acacia pellita* showed selective enrichment of amino acids and hydrolysable NH_4^+-N. The N added under the trees, like *Prosopis juliflora*, nitrified after a longer delay period than in cultivated soils. It was concluded that identifying the species that were more suitable to companion crops under agroforestry system and N management was crucial for efficient N utilization.

Uday Burman *et al.* (2002) reported that the total nitrogen content improved largely over tree cover when compared to cultivated field. Manjunatha *et al.* (2002) noticed that the plantations like *Acacia ferugenia*, *Albizzia lebbeck* and *Gliricidia maculate* enriched the soil nutrient pool (NPK).

Sarawad and Dhyan Singh (2005) conducted a long term fertilizer experiment set up on a *Typic Haplustept* in 1971 on the farm of Indian Agricultural Research Institute, New Delhi, with maize-wheat-cowpea cropping sequence. They reported that long-term application of 100 % NPK + FYM resulted in the highest amount of total N in soil which was closely followed by 150 per cent NPK. The values progressively increased with increase in the level of NPK from 50 to 150 per cent of optimal dose. The increase in total N content from 1496 kg ha^{-1} to 1524 kg ha^{-1} before sowing of maize and at after harvest of cowpea respectively.

Xu *et al.* (2007) noticed that soil total N was increased after 18 years of fertilization. On an average, the total soil N in the 0 to 20 cm soil layer for all fertilization treatments was 1.48 g kg^{-1}, whereas it was 1.29 g kg^{-1} at the beginning of the experiment, which was an increase of 14.7 per cent. Total input of 5400 kg N ha^{-1} during 18 years of the experiments contributed to a very high difference in total soil N of different fertilization treatments. In the top 5 cm soil layer, supplementation of reduced input of chemical N fertilizer by straw and pig manure increased total soil N by 19 per cent and 28 per cent as compared with the application of inorganic N alone. Organic C and total N

contents of soils from different treatments were found in the order of pig manure plus inorganic fertilizer > straw plus inorganic fertilizer > inorganic fertilizer > control.

In a study on luvisols under agroforestry and conventional systems in semi-arid zone of Brazil, Maia *et al.* (2008) examined the N fractions and reported that conventional cropping had the lowest total N under both the soil depths and maximum was observed under traditional agroforestry which was significantly higher than all other land use systems in both soil depths (0–6 cm and 6–12 cm).

Mao and Zeng (2010) studied the effects of marginal agricultural land in a semi-arid area of Northeast China and found that soil total N concentration and potential N mineralization rates decreased initially following afforestation of agricultural lands and then increased with stand development. However, potentially mineralizable–N concentration showed no significant changes in the first 10 years following afforestation and then increased with stand age. They proposed that change in soil quality with stand age should be considered in determining optimum rotation length of plantation and best management practices for afforestation programme.

Mao *et al.* (2010) investigated the changes in total N stock in 100 cm soil depth following afforestation of marginal agricultural land using a chronosequence of poplar in Northeast China. They found that total N concentration in 45–60 cm layer increased gradually following afforestation of agricultural land whereas in 60–100 cm layer, it declined initially and then increased with stand development. Based on volume and mass based method, such land use change caused initial decline in total N stock and then increased between the stand age of 10 and 20 years.

Amrita Chakraborty *et al.* (2011) reported that the total nitrogen content of soil was significantly highest in the 100% RD of NPK + FYM treatment (1.16 g kg^{-1}). The other mineral fertilizer treatments as well as the untreated control had statistically similar values of total N content of soil, although higher fertilizer doses correspond to higher values. The variation in organic C content of soil with the application of different treatments also followed a similar trend as that of the total N content of the soil. The

highest accumulation of organic C occurred with 100% RD of NPK + FYM, while the other treatments had little difference between themselves. Manure application in combination with mineral fertilizer increased the total N content and enriched soil organic matter content than the exclusive mineral fertilizer treatments.

Di Bene *et al.* (2011) studied the changes in soil quality under 1, 2 and 3 year cutting cycles of poplar with an intensive food cropping system (wheat-soybean rotation). They found that in the 0–10 cm soil depth total N, P and SOC were significantly affected by the management. Poplar short rotation forestry (SRF) resulted in an increase of total N by 11–34% as compared to soybean-wheat. The highest increase was observed in the 3rd cutting cycle.

Daniele *et al.* (2013) reported that soil total nitrogen concentrations varied widely among different land uses (from 0.58 to 1.14 g kg^{-1} in the 0–10 cm layer and from 0.29 to 0.55 g kg^{-1} in the 10–30 cm layer). Total nitrogen values were greater at the soil surface than at depth. The soil under integrated coconut cultivation showed best results, presenting 34% more total nitrogen than the native forest soil, probably as a result of good management practices and application of N as both inorganic and organic amendments. Ravikumar and Somashekar (2013) reported the decrease in the total nitrogen content with increase in depth which might be related to the close link with organic carbon and due to association of nitrogen with organic matter and adsorption of ammonical nitrogen on humus complex in the soil.

The contents of total N in grassland were also the highest in the order of grassland (0.145%) > woodland (0.130%) > farmland (0.117%), both in the reed-bed soils were the lowest. Nitrogen in the natural soils was mainly from the decomposition and mineralization of organic matters, nitrogen fixation and atmospheric deposition. The main outputs of nitrogen included plant uptake, immobilization, leaching, ammonia volatilization and denitrification (Yong-Tao Zhang *et al.,* 2013).

The mean nitrogen stocks in soils of the Lena River Delta (Arctic) for the upper 1 m of soils were estimated at 1.2 kg m^{-2}± 0.4 kg m^{-2} for the Holocene river terrace and at

0.9 kg m^{-2}± 0.4 kg m^{-2} for the active floodplain levels, respectively. For the depth of 1 m, the total N pool of the river terrace was estimated at 4.8 Tg ± 1.5 Tg and the total N pool of the floodplains was estimated at 7.7 Tg ± 3.6 Tg (Zubrzycki *et al.,* 2013).

Total nitrogen was the highest (0.44% in topsoil and 0.21% in subsoil) under forestland and was the lowest (0.14% in topsoil and 0.11 % in subsoil) under bush land. Similar to organic matter, the percentage changes in total nitrogen content of subsoil from topsoil were decreasing in all land uses. Thus, total nitrogen is higher in topsoil than in the subsoil probably be as a result of losses in organic matter by mineralization in the subsoil (Adugna and Abegaz, 2015).

Shehnaz Sharma *et al.* (2015) reported that total N stock was the lowest in poplar with one cutting cycle (2.72 Mg ha^{-1}) which increased significantly in poplar with four cutting cycle (6.03 Mg ha^{-1}) in the 0–15 cm soil depth. Correspondingly, in the 15–30 and 30–45 cm layers, it increased from 3.76 to 6.59 and 2.84 to 4.68 (Mg ha^{-1}), respectively. Soil ammonical nitrogen improved with increase in number of cutting cycles of poplar.

Soil total nitrogen stocks were significantly influenced by slope position and land use types. the average mean value of total nitrogen stocks were 10.31, 7.54 and 4.23 t/ha for lower, middle and upper slope position respectively. The result revealed that soil total nitrogen stocks were significantly decreased from lower to upper slope positions. Regarding to land use types, total nitrogen stock 1.67, 12.19, 8.22 t/ha for cultivated, enset woody land, respectively (Bahilu Bezabih *et al.,* 2016).

Irrespective of depth total nitrogen was significantly higher in 100% + FYM + lime (472 mg kg^{-1}) followed by 100% + FYM as compared to rest of treatments in a long term fertilizer experiment at GKVK, Bangalore. Among different depths total nitrogen was significantly higher at 0 to 15 cm depth as compared to deeper layers (Gangamrutha, 2016).

The total N (TN) contents in both farmland and grassland in Tibet decreased with soil depth. The TN contents in the 0–5 cm and 40–50 cm layers of the farmland were 0.55±0.21 and 0.30±0.11 g/kg, respectively, corresponding to a reduction of 45.45%. The

TN coefficient of variation in the 0–50 cm layer was 21.30%. However, the variability of the TN content in the 0–30 cm layer decreased at 8.03%. The differences in TN content among the 0–5, 5–10, 10–20 and 20–30 cm layers were not significant. Conversely, the differences in TN content between the 0–5 and 5–10 cm layers and between the 30–40 and 40–50 cm layers were significant (Liu Heman *et al.,* 2016).

Marty *et al.* (2017) reported that total nitrogen concentration in the forest floor (FF) ranged from 7.1 g N kg^{-1} at General White to 21.1 g N kg^{-1} at Lemaine and averaged 16.7 g N kg^{-1} across the 21 sites forests of eastern Canada. Nitrogen concentration was significantly lower in the mineral soil horizons than in the FF. It ranged from 0.2 g N kg^{-1} in the C-horizon at Boisvert to 6.4 g N kg^{-1} in the B1-horizon at Desjoncs and averaged 1.3 g N kg^{-1} across all mineral horizons. Total N pools in both the organic and mineral horizons are among the highest reported for temperate and boreal forests.

Purnananda *et al.* (2017) showed that soils under coconut land use system the total nitrogen content in the soils decreased with depth from 407 to 334.52 ppm. Soil under arecanut land use system showed that the higher total nitrogen (316.74 ppm) was recorded in surface lower (270.85 ppm) was in sub surface soils. Total nitrogen content in soils under pomegranate land use system decreased with depth with lowest and highest value being 230.74 ppm and 515.94 ppm, respectively. The decrease in the total nitrogen content with increase in depth may be related to the close link with organic carbon and due to association of nitrogen with organic matter and adsorption of ammonical nitrogen on humus complex in the soil.

2.4.5 Correlation studies

Asit Mandal *et al.* (2007) reported the existence of a significant positive relationship between the soil enzyme activities. They observed that mineralizable N at tillering (R^2=0.80), MBC at flowering (R^2=0.90) and alkaline phosphatase activity (R^2=0.70) at dough stages were significant at the respective stages to predict the grain yield of wheat crop. Improved organic matter, higher substrate availability and microbial biomass carbon status of soil results in higher enzyme activity. This reflects the greater

biological activity in soil and the stabilization of extracellular enzymes through complexation with humic substances (Basak *et al.,* 2013).

Hatti *et al.* (2008) reported that the SOC content at 0 to 30 cm soil depth showed a highly significant and positive linear relationship with mean weight diameter and total porosity and a highly significant negative linear relationship with bulk density of the soil. The coefficient of determination values showed that SOC explained 50, 52 and 45 per cent of the variability for mean weight diameter, total porosity and bulk density, respectively. The SOC content also had a significant positive relationship with soil pH. With an increase in pH by addition of lime and FYM, the soil physical attributes of acidic soil improved and enhanced nutrient availability which increased crop productivity and further added more biomass residues to soil.

Wei *et al.* (2008) reported that soil carbon fractions were significantly positively correlated with each other and with carbon management index (CMI). The results indicated that there were close relationships between CMI and carbon fractions of contents, available nutrient contents and the activity of soil enzyme.

Jiao *et al.* (2009) reported that the SOC contents for the soil of 0-10 cm, 10-20 cm and 20-30 cm was 3.37, 2.89 and 2.11% in the grassland and 2.55, 2.27 and 1.55 in the forest soils. They also indicated that SOC content were positively dependent on total nitrogen content, but negatively on bulk density or land use type. Li *et al.* (2009) reported that the mineralized C had a significant positive relationship with the mineralized P, and the microbial biomass C and P were significantly positively correlated with soil organic C and P.

Papini *et al.* (2011) observed that the correlation coefficients of soil pH, bulk density (BD), cation exchange capacity (CEC), total N and exchangeable K were closely related to SOC content; in contrast, they showed no significant relationships to soil particle size. In particular, all SOC pools were positively related to soil total N, CEC and exchangeable K, and negatively related to soil pH and BD.

Ibrahim Ortas and Rattan Lal (2012) found that there was a negative and significant correlation between MWD and soil bulk density and a positive correlation between MWD and total porosity and SOC concentration. The correlation between bulk density and SOC concentration was significantly negative. Concentration of total soil nitrogen was positively correlated with those of SOC and total C but not with bulk density.

Liu *et al*. (2013) revealed that particulate organic matter (POC), microbial biomass carbon (MBC) and water soluble carbon (WSC) concentrations increased linearly with increasing soil SOC content, suggesting that total organic matter content was a major determinant of the amount of POC, MBC and WSC present. They also noticed that of the reported C pools, POC was highly correlated with SOC, followed by MBC then WSC.

Kumar *et al.* (2014) studied the grid based (GPS) surface (0–15 cm) soil samples by systematic survey were collected from 4 blocks, 84 selected villages in Kabeerdham district were 297 samples identified from *Vertisol*. The results revealed that available N had significant positive correlation with organic C. Most of the soil nitrogen as estimated based on the organic matter present in the soil. There is a definite relation of organic C with available N because organic matter releases the mineralizable N in a proportionate amount present in the soil. Hence, organic carbon status of the soil can predict the available N which showed positive relationship.

Monisa Raza (2015) studied soil samples collected from surface (0–15 cm) and sub-surface (15–30 and 30–45 cm) under four land uses namely agriculture, forest, horticulture and grassland. The results showed that CEC was positively correlated with total organic carbon, total carbon, water soluble carbon, microbial carbon, organic carbon, very labile and less labile carbon in the surface and subsurface layer.

Patil *et al.* (2015) concluded that soil pH and available phosphorus were negatively correlated which may be due to conversion of soluble phosphorus to insoluble calcium and magnesium phosphate thus reducing its availability with the rise in soil pH.

Bindu Sharma and Sujata Bhattacharya (2017) revealed that bulk density had a negative correlation with the organic carbon (r = -0.136) and organic matter (r = -0.176). This indicates that organic matter increases when bulk density decreases as in which is required for proper growth of the plant.

Conclusion

To conclude the literature reviewed, agri–horticulture which is a system of growing trees along with crops has a great potential for carbon sequestration both through storage in aboveground biomass and belowground addition through litterfall and roots. The belowground addition contributes significantly towards increasing the soil organic carbon content. The quantity and quality of soil organic carbon, however, depends upon type of tree plantation, quality of litter, age of plantation, soil texture, climate and other agricultural management practices. The labile fractions of C are important for improving the nutrient supply and other physico-chemical characteristics of soils, whereas, recalcitrant fraction is important for long term sequestration of C in soil. These fractions have also been suggested as sensitive indicators of change in land use on SOC sequestration. Similarly, agroforestry positively affects the nitrogen content and its availability in soil. Nitrogen, being an important part of SOM, generally increases under tree plantations. The macronutrients as well as micronutrients generally are higher under the tree species as compared to agricultural crops alone. But there can be variations according to the initial state of soil, climate and other factors. The physico-chemical properties of soil such as water holding capacity, cation exchange capacity, bulk density, aggregation etc. are generally found to improve under the higher age tree plantations. The intercropping system helps in efficient land utilization, increased profit per unit land, productivity and also serves as insurance during aberrant weather conditions and trade manipulations and price fluctuations. In view of this, the present investigation was envisaged to explore the possibility of intercropping in custard apple based agri–horti with the field crops (finger millet, fodder maize, field bean, niger, cow pea and foxtail millet) under dryland conditions in Eastern Dry Zone of Karnataka in *Alfisols.*

III MATERIAL AND METHODS

The details of the materials used and the techniques adopted in the study entitled "**Carbon and nitrogen dynamics under agri–horticulture system**" conducted during *kharif* seasons of 2017 and 2018 are presented in this chapter.

3.1 Location of the experimental site

The field experiment was conducted at the All India Coordinated Research Project for Dryland Agriculture (AICRPDA), Gandhi Krishi Vignana Kendra (GKVK), University of Agricultural Sciences (UAS), Bangalore, situated in the agro–climatic zone V (Eastern Dry Zone) of Karnataka at 12°58' North latitude and 77°35' East longitude with an altitude of 930 m above mean sea level. The present study was carried out in an ongoing experiment "Evaluation of custard apple based agri-horti system involving cereals and pulses" which was initiated in *kharif* 2012 in a custard apple orchard which was planted during 2009 with 15 treatments.

3.2 Initial soil characteristics of the experimental site

The soil of the experimental site was classified under the order *Alfisols.* The initial soil properties (as recorded in 2012) of the experimental site (Ramulu, 2014) revealed that the soil was sandy clay loam in texture (coarse sand 36.08 %, fine sand 29.06 %, silt 6.75% and clay 28.11 %) with a bulk density of 1.47 Mg/m^3. Soil was slightly acidic (pH–5.6) in reaction with low organic matter (0.40%) content with normal electrical conductivity (0.07 dS m^{-1}). The soil was low in available nitrogen (224.0 kg ha^{-1}), high in phosphorus (72.0 kg ha^{-1}) and medium in potassium (163.0 kg ha^{-1}).

3.3 Climatic conditions

The normal as well as actual weather data on total rainfall, maximum and minimum temperature that prevailed during the period of experimentation are presented in Table 3.1 and 3.2 and graphically depicted in Fig. 3.1a and 3.1b.

Table 3.1: Meteorological data of the experimental area during 2017 and the normal values at GKVK, Bangalore

Year/ Months	Rainfall (mm)			Mean temperature (°C)						Mean relative humidity (%)			Mean sunshine hours (hr day^{-1})			Mean wind speed (km hr^{-1})			Pan evaporation (mm day^{-1})		
				Maximum			Minimum														
2017	**N**	**A**	**D**	**N**	**A**	**D**	**N**	**A**	**D**	**N**	**A**	**D**	**N**	**A**	**D**	**N**	**A**	**D**	**N**	**A**	**D**
January	1.4	0.0	-1.4	26.8	27.3	0.5	13.7	14.5	0.8	84.0	88.9	4.9	8.6	8.2	-0.4	6.6	7.3	0.7	4.9	3.5	**-1.4**
February	8.8	0.0	-8.8	29.1	30.6	1.5	14.9	13.5	-1.4	78.7	84.2	5.5	9.1	10.1	1.0	6.6	7.7	1.1	6.0	4.0	**-2.0**
March	16.6	9.8	-6.8	31.8	33.0	1.2	17.6	19.5	1.9	73.7	82.7	9.0	9.0	8.9	-0.1	6.7	6.9	0.2	7.3	4.3	**-3.0**
April	47.1	1.6	-45.5	33.0	35.1	2.1	20.0	21.2	1.2	77.4	83.1	5.7	8.7	8.4	-0.3	6.5	7.1	0.6	7.4	4.6	**-2.8**
May	101.3	246.8	145.5	32.3	32.7	0.4	20.0	20.7	0.7	79.7	85.3	5.6	8.0	7.6	-0.4	7.9	7.8	-0.1	6.9	4.3	**-2.6**
June	80.1	64.4	-15.7	28.8	28.6	-0.2	19.1	19.5	0.4	83.9	89.5	5.6	5.5	5.2	-0.3	12.4	10.6	-1.8	5.8	4.6	**-1.2**
July	106	33.4	-72.6	27.4	28.8	1.4	18.6	19.8	1.2	86.1	89.1	3.0	4.2	5.0	0.8	11.8	10.5	-1.3	5.1	3.7	**-1.4**
August	127.5	198.5	71.0	26.9	28.2	1.3	18.5	20.0	1.5	86.9	91.2	4.3	4.6	3.9	-0.7	10.1	7.8	-2.3	4.7	3.3	**-1.4**
September	193.3	275.6	82.3	27.3	27.7	0.4	18.3	19.6	1.3	86.7	90.6	3.9	5.5	5.2	-0.3	6.9	6.0	-0.9	4.8	3.2	**-1.6**
October	162.7	264.4	101.7	27.2	28.1	0.9	17.8	19.0	1.2	85.8	91.0	5.2	5.9	6.0	0.1	5.3	4.2	-1.1	4.6	3.2	**-1.4**
November	57.1	10.0	-47.1	26.1	26.9	0.8	16.1	17.5	1.4	82.5	90.8	8.3	6.1	5.4	-0.7	5.9	6.4	0.5	4.4	3.0	**-1.4**
December	13.2	6.4	-6.8	25.6	26.3	0.7	14.2	14.9	0.7	82.4	90.2	7.8	7.0	6.9	-0.1	6.7	5.9	-0.8	4.4	3.0	**-1.4**
Total/ Mean	**915.0**	**1110.9**	**195.9**	**28.5**	**29.4**	**0.9**	**17.4**	**18.3**	**0.9**	**82.3**	**88.1**	**5.8**	**6.9**	**6.7**	**-0.2**	**7.8**	**7.4**	**-0.4**	**5.5**	**3.7**	**-1.8**

Note: **N**- Normal meteorological data (mean of 1975 – 2016), **A** - Actual meteorological data, **D** - Deviation from the normal (A-N)

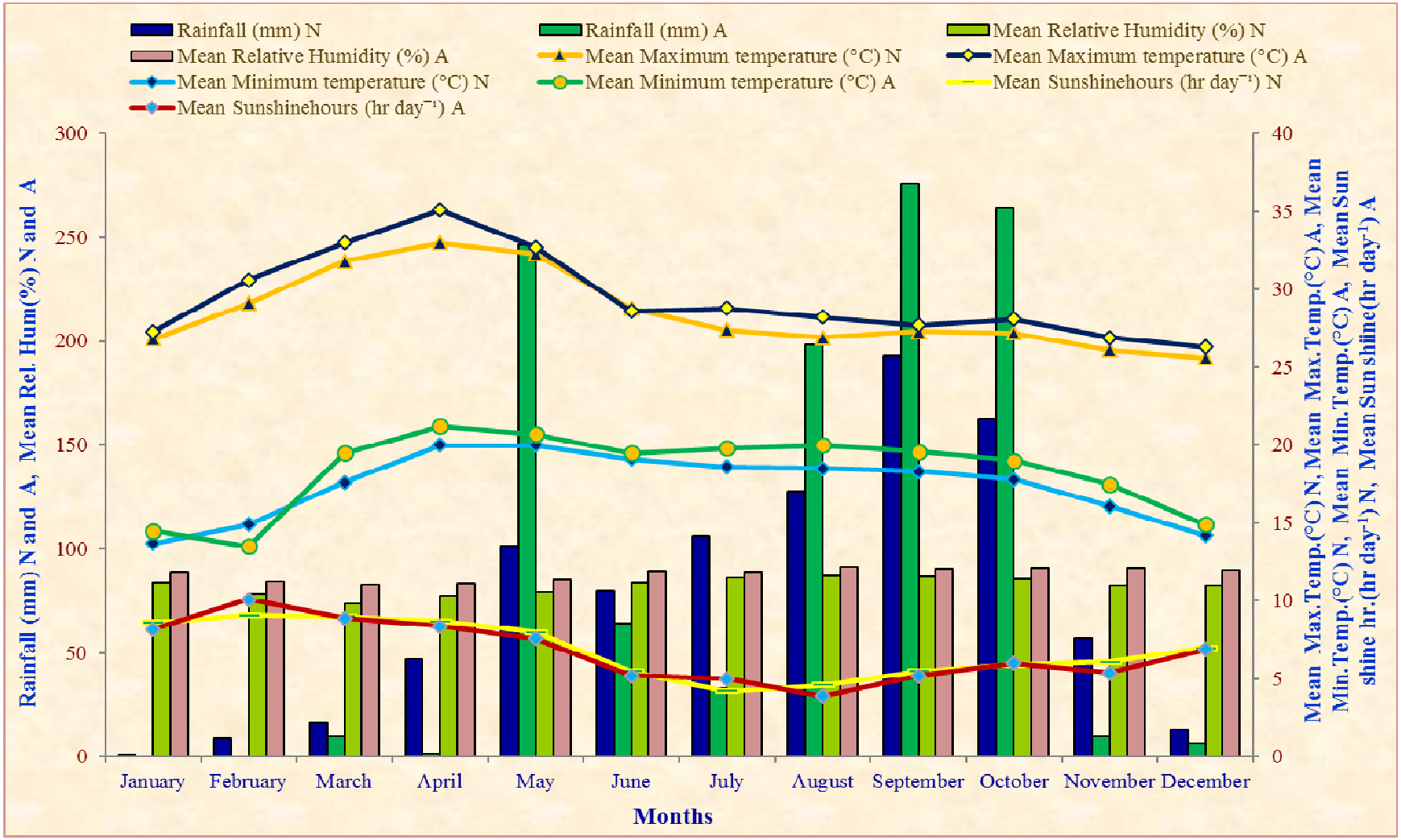


Fig. 3.1a: Meteorological data of the experimental area during 2017 and normal climatic values of GKVK, Bengaluru

Table 3.2: Meteorological data of the experimental area during 2018 and the normal values at GKVK, Bangalore

Year/ Months	Rainfall (mm)			Mean temperature (°C)						Mean relative humidity (%)			Mean sunshine hours (hr day^{-1})			Mean wind speed (km hr^{-1})			Pan evaporation (mm day^{-1})		
				Maximum			Minimum														
2018	**N**	**A**	**D**	**N**	**A**	**D**	**N**	**A**	**D**	**N**	**A**	**D**	**N**	**A**	**D**	**N**	**A**	**D**	**N**	**A**	**D**
January	1.4	0.0	-1.4	26.8	27.4	0.6	13.7	14.1	0.4	84.1	86.9	2.8	8.6	8.7	0.1	6.6	5.4	-1.2	4.9	4.8	**-0.1**
February	8.6	3.0	-5.6	29.1	29.4	0.3	14.9	15.4	0.5	78.8	86.2	7.4	9.1	9.3	0.2	6.6	7.5	0.9	6.0	5.8	**-0.2**
March	16.4	62.2	45.8	31.8	32.0	0.2	17.6	17.7	0.1	73.9	78.5	4.6	9.0	8.5	-0.5	6.7	6.9	0.2	7.2	7.8	**0.6**
April	46.0	37.0	-9.0	33.0	33.2	0.2	20.0	20.8	0.8	77.5	83.0	5.5	8.7	8.0	-0.7	6.5	6.0	-0.5	7.3	6.8	**-0.5**
May	104.7	229.4	124.7	32.3	31.7	-0.6	20.0	19.8	-0.2	79.8	86.1	6.3	8.0	7.3	-0.7	7.9	5.1	-2.8	6.8	5.0	**-1.8**
June	79.7	29.6	-50.1	28.8	28.5	-0.3	19.1	19.7	0.6	84.0	90.6	6.6	5.5	5.0	-0.5	12.4	9.1	-3.3	5.8	4.3	**-1.5**
July	104.3	62.6	-41.7	27.4	27.7	0.3	18.6	19.4	0.8	86.2	91.9	5.7	4.2	3.9	-0.3	11.8	9.9	-1.9	5.1	3.6	**-1.5**
August	129.2	97.8	-31.4	26.9	27.0	0.1	18.5	18.8	0.3	87.0	94.5	7.5	4.6	3.5	-1.1	10.0	9.0	-1.0	4.7	3.0	**-1.7**
September	195.2	153.6	-41.6	27.3	29.3	2.0	18.3	19.2	0.9	86.8	91.7	4.9	5.5	6.4	0.9	6.9	4.8	-2.1	4.8	3.8	**-1.0**
October	165.1	29.2	-135.9	27.2	29.0	1.8	17.8	17.9	0.1	85.9	90.5	4.6	5.9	7.6	1.7	5.3	5.4	0.1	4.6	4.2	**-0.4**
November	56.0	20.6	-35.4	26.1	28.4	2.3	16.1	16.9	0.8	82.7	89.6	6.9	6.1	7.4	1.3	5.9	7.3	1.4	4.4	4.0	**-0.4**
December	13.0	2.8	-10.2	25.6	29.3	3.7	14.2	18.1	3.9	82.6	88.1	5.5	7.0	6.9	-0.1	6.7	6.9	0.2	4.4	4.8	**0.4**
Total/ Mean	**919.7**	**727.8**	**-191.9**	**28.5**	**29.4**	**0.9**	**17.4**	**18.2**	**0.7**	**82.5**	**88.1**	**5.7**	**6.8**	**6.9**	**0.0**	**7.8**	**6.9**	**-0.8**	**5.5**	**4.8**	**-0.7**

Note: **N**- Normal meteorological data (mean of 1975 – 2017), **A** - Actual meteorological data, **D** - Deviation from the normal (A-N)

3.3.1 Normal climatic conditions

Normal annual rainfall of GKVK, Bangalore was 915.0 mm. The major portion of rain was received during May to November with two peaks in the months of May and September. The mean maximum air temperature ranged from 25.6°C (December) to 33.0°C (April) and mean minimum air temperature ranged between 13.7°C (January) to 20.0°C (April–May). The highest mean temperature (33.0°C) was recorded during April and it was followed by May (32.3°C). The mean monthly relative humidity ranged from 73.7 per cent in March to 86.9 per cent during August month. The mean monthly open pan evaporation gradually decreased from April to December (from 7.4 to 4.4 mm). The mean wind speed ranged from 5.3 to 12.4 km per hour. The mean monthly maximum sunshine hour was maximum during February (9.1 hr day^{-1}) followed by March (9.0 hr day^{-1}).

3.3.2 Actual weather conditions during the period of experimentation

The total annual rainfall received during 2018 (727.8 mm) was less as compared to 2017 (1110.9 mm) and normal rainfall (915.0 mm). The crop growth period was from July to November in both the years. During the crop growth period, September month recorded higher rainfall (275.6 and 153.6 mm during 2017 and 2018, respectively).

The mean maximum air temperature was higher in the month of April both during 2017 (35.1°C) and 2018 (33.2°C). The mean minimum temperature was recorded higher than normal for most of the months. The mean monthly relative humidity ranged from 82.7 per cent in March to 91.2 per cent in August during 2017, while it ranged from 78.5 per cent during March to 91.9 per cent in July during 2018.

The mean pan evaporation ranged from 3.0 mm per day in November to 4.6 mm per day in April 2017 and 3.0 mm per day in August and 7.8 mm per day in March 2018. Monthly wind speed during 2017 varied between 4.2 to 10.6 km per hour during October and June months, respectively, whereas during 2018, it varied between 4.8 km per hour in September to 9.9 km per hour in July.

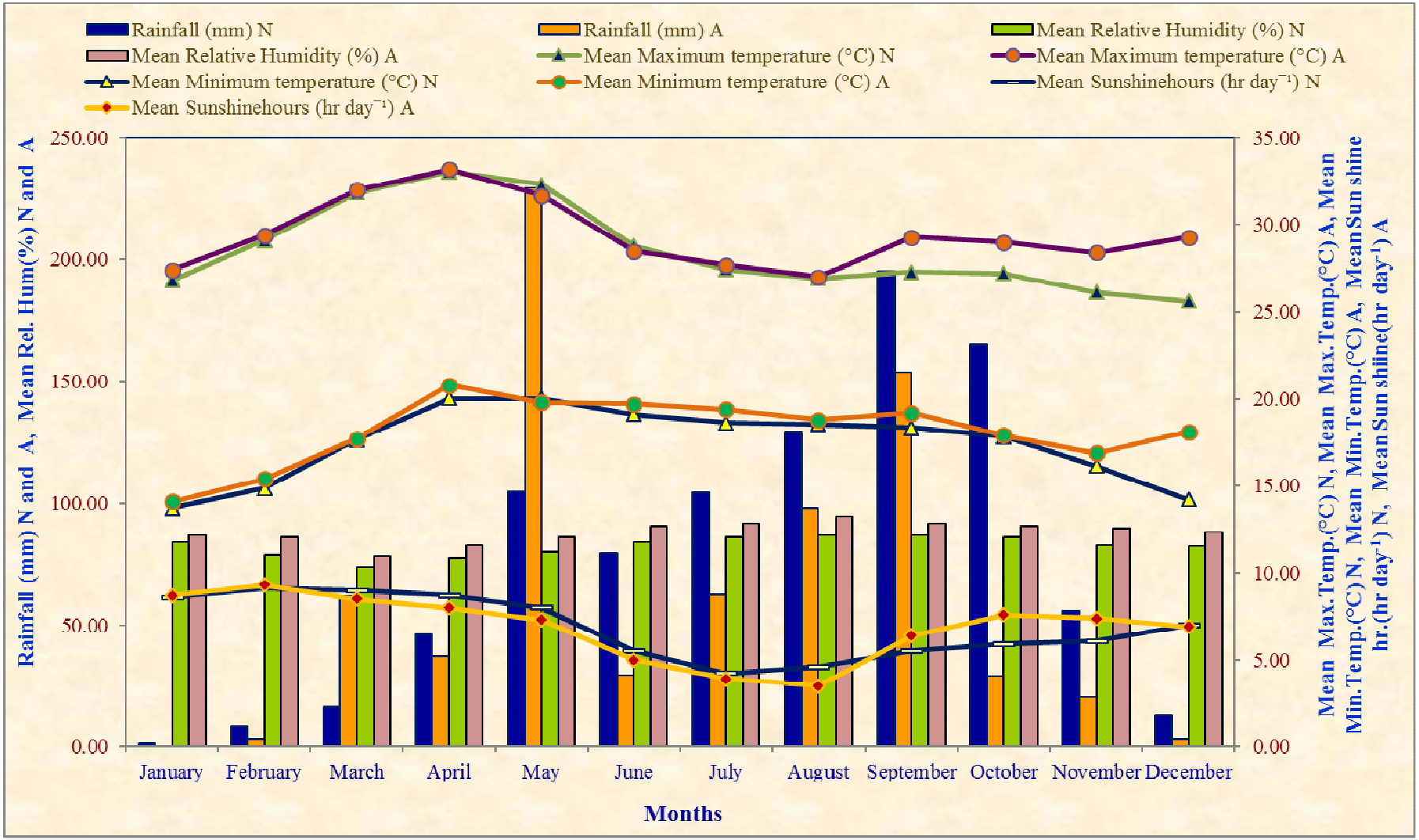


Fig. 3.1b: Meteorological data of the experimental site during 2018 and normal climatic values of GKVK, Bengaluru

The mean sunshine hours were highest in February month (10.1 and 9.3 hr day^{-1}, respectively) during both the years. The lowest hour of sunshine was noticed in July (5.0 hr day^{-1}) during 2017 and in August (3.5 hr day^{-1}) during 2018.

3.4 Experimental details

The details of the field experiment carried out during *Kharif* 2017 and *Kharif* 2018 in nine year old custard apple field are detailed below.

3.4.1 Experiment, design and treatment details

The present study was conducted during *kharif* 2017 and 2018 with 15 treatments replicated thrice adopting randomized complete block design. The plan of layout of experiment is depicted in Fig. 3.2 and general view of the experimental site is presented in Plate 3.1. The treatment details along with spacing and fertilizer recommendation is as prescribed at below.

Treatments details	**Spacing**	**Recommended dose of fertilizer (N:P:K)**	
		CA (g $plant^{-1}$)	**Intercrops (kg ha^{-1})**
T_1: CA + Finger millet	30 cm x 10 cm	250:125:125	50:40:25
T_2: CA + Fodder maize	30 cm x 15 cm	250:125:125	100:50:50
T_3: CA + Field bean	45 cm x 30 cm	250:125:125	25:50:25
T_4: CA + Niger	30 cm x 10 cm	250:125:125	20:40:20
T_5: CA + Chilli	45 cm x 45 cm	250:125:125	100:50:50
T_6: CA + Cowpea	45 cm x 15 cm	250:125:125	25:50:25
T_7: CA + Foxtail millet	30 cm x 10 cm	250:125:125	40:40:00
T_8: Finger millet	30 cm x 10 cm	------	50:40:25
T_9: Fodder maize	30 cm x 15 cm	------	100:50:50
T_{10}: Field bean	45 cm x 30 cm	------	25:50:25
T_{11}: Niger	30 cm x 10 cm	------	20:40:20
T_{12}: Chilli	45 cm x 45 cm	------	100:50:50
T_{13}: Cowpea	45 cm x 15 cm	------	25:50:25
T_{14}: Foxtail millet	30 cm x 10 cm	------	40:40:00
T_{15}: Custard apple alone	5.0 m x 5.0 m	250:125:125	------

Note: CA–Custard apple

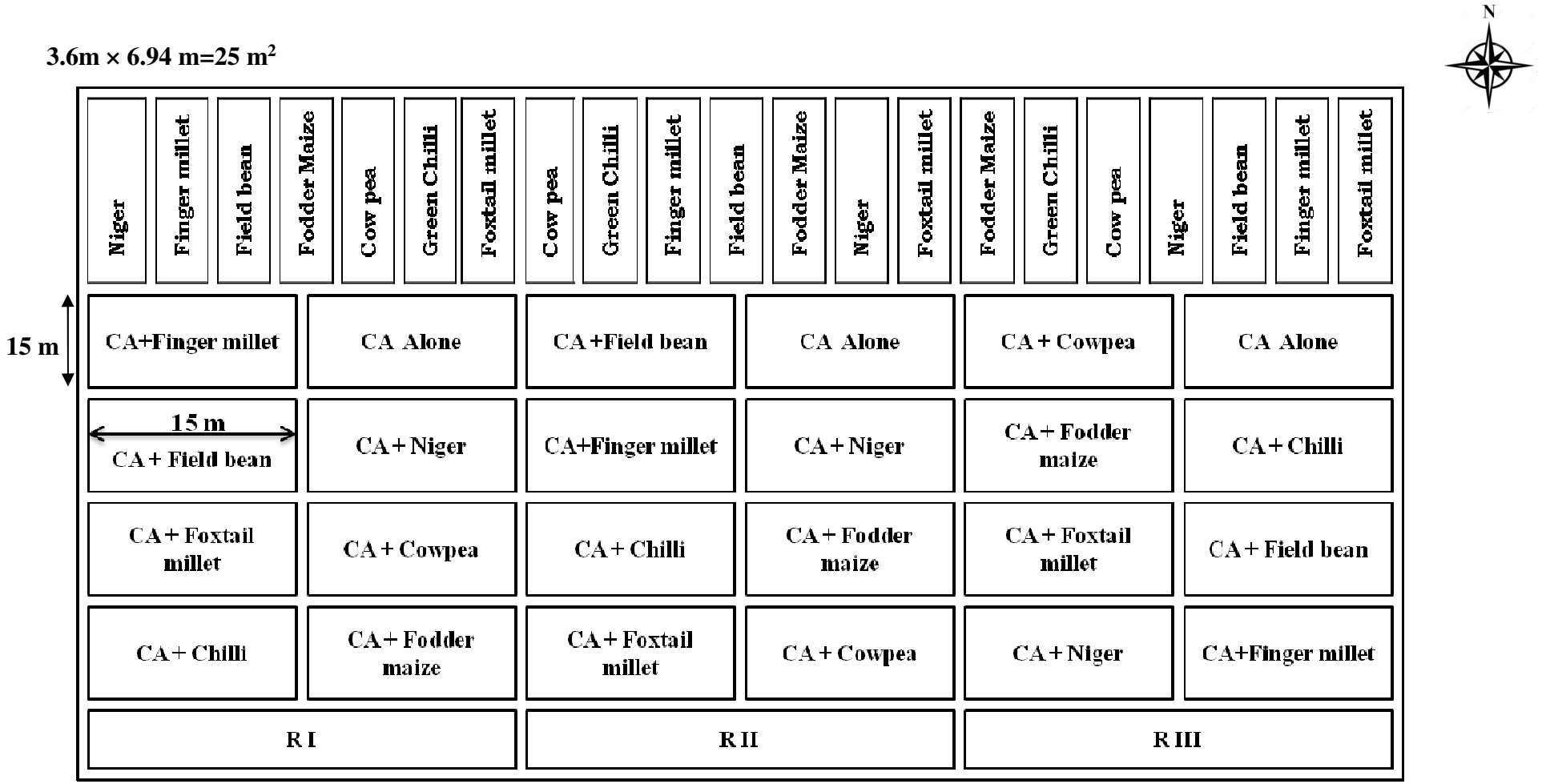
3.4.2 Crop, variety and hybrid

Crops	Variety	Seed rate (kg ha^{-1})
Custard apple	Arka Sahana	400 plants ha^{-1}
Finger millet	GPU–28	12.5
Fodder maize	S. A.Tall	55.0
Field bean	Hebbal avare–4	30.0
Niger	No. 71	1.50
Chilli	Samruddhi	1.25
Cowpea	IT 98456–1	25.0
Foxtail millet	R.S–118	7.00

3.4.3 Plot size

Treatments	Specification	
	Gross plot	Net plot
T_1: CA + Finger millet	15 m x 15 m = 225 m²	13.8 m x14.6 m = 201.48 m²
T_2: CA + Fodder maize	15 m x 15 m = 225 m²	13.8 m x14.4 m = 198.72 m²
T_3: CA + Field bean	15 m x 15 m = 225 m²	13.05 m x13.8 m = 180.09 m²
T_4: CA + Niger	15 m x 15 m = 225 m²	13.8 m x14.6 m = 201.48 m²
T_5: CA + Chilli	15 m x 15 m = 225 m²	13.05 m x13.05 m = 170.30 m²
T_6: CA + Cowpea	15 m x 15 m = 225 m²	13.05 m x14.4 m = 189.72 m²
T_7: CA + Foxtail millet	15 m x 15 m = 225 m²	13.8 m x14.6 m = 201.48 m²
T_8: Finger millet	3.6 m x 6.94 m = 25 m²	2.4 m x 6.5 m = 15.6 m²
T_9: Fodder maize	3.6 m x 6.94 m = 25 m²	2.4 m x 6.3 m = 15.12 m²
T_{10}: Field bean	3.6 m x 6.94 m = 25 m²	1.8 m x 5.7 m = 10.26 m²
T_{11}: Niger	3.6 m x 6.94 m = 25 m²	2.4 m x 6.5 m = 15.6 m²
T_{12}: Chilli	3.6 m x 6.94 m = 25 m²	1.8 m x 4.95 m = 8.91m²
T_{13}: Cowpea	3.6 m x 6.94 m = 25 m²	1.8 m x 6.93 m = 11.34 m²
T_{14}: Foxtail millet	3.6 m x 6.94 m = 25 m²	2.4 m x 6.5 m = 15.6 m²
T_{15}: Custard apple alone	15 m x 15 m = 225 m²	15 m x 15 m = 225 m²

Note: CA: Custard apple



Note: CA: Custard apple

Fig. 3.2: Plan of layout of the experiment



Plate 3.1: General views of experimental plot with custard apple

3.5 Cultural operations

3.5.1 Land preparation

The land was prepared for experiment by ploughing with disc plough once and later by passing cultivator twice followed by final harrowing to bring the soil to fine tilth condition. The land was prepared and laid out into different plots of required size for both intercrops and sole crops. Small bunds were constructed around each plot and replication to avoid cross movement of water and nutrients from one plot to another.

3.5.2 Fertilizer application

The details of the recommended dose of fertilizer applied for each crop including custard apple is depicted in section 3.4.1. Well decomposed farmyard manure @ 7.5 t ha^{-1} was applied as per the treatment specifications two weeks before transplanting/sowing of the crops and mixed thoroughly with soil. The nutrients were applied in the form urea, single super phosphate and muriate of potash. The fertilizers were band placed at 5 cm away from the seed row and thoroughly mixed in the soil.

3.5.3 Main crop: Custard apple

Custard apple hybrid Arka Sahana was released in 1997 at ICAR–IIHR Hesaraghatta, Bangalore. Fruits of Arka Sahana are remarkable for scarce small seeds, sweetness (>32°B: 22.8% total sugar) and is a slow ripening one (5–6 days). The pulp of the fruit is snow–white and juicy with a mild pleasant aroma. Nutritionally, on an average a 100 g pulp of fruit contains 2.49 g of crude protein, 42.29 mg of phosphorus and 225 mg of calcium.

As many as 80 per cent of the pollinated flowers produce fruits that will stay until harvest, and as compared to open pollinated fruits weigh about 90 per cent more (450–500 g) and possess almost uniform shape with no loss in edible fruit attributes. Since Arka Sahana flowers are big, hand pollination is relatively easy and fast. One can pollinate 150–200 flowers/ hour. Eight years onwards a tree of Arka Sahana can produce 40–45 kg fruits, hence in each tree about 150 flowers should be hand pollinated to achieve an expected yield of 25 tonnes ha^{-1}. Pollens of previous day opened flowers were

collected in a plastic cup and dip the clean dry paint brush (No. 2 or 3) into the plastic cup containing pollens smear on the stigma of Arka sahana flowers.

3.5.4 Planting, sowing and transplanting

In an already established eight years old custard apple (planted in 2009) orchard intercrops along with sole crops were taken for study. The bold and healthy seeds of finger millet, fodder maize, field bean, niger, cowpea and foxtail millet were selected for sowing. The seeds were sown in rows by maintaining recommended row spacing. Later by thinning, intra row spacing was maintained. The first season sowing was done on 22-08-2017 and second season sowing was done on 13-08-2018**.** Chilli seeds were sown in nursery bed and the seedlings (21 days old) were transplanted from the nursery bed to the main field. The intercrops *viz,* finger millet, fodder maize, field bean, niger, chilli, cowpea and foxtail millet were sown at their respective spacing as sole crops.

3.6 After care

3.6.1 Gap filling and thinning

After eight days of sowing, gap filling was carried out in order to maintain optimum plant population. Thinning was carried out after 15 days of emergence of the seedlings. Thinning and gap filling were done manually to maintain optimum plant population.

3.6.2 Intercultivation and weeding

Hand weeding was done at 15 and 30 DAS/DAT for all the crops. Intercultivation was done once using blade hoe at 45 DAS. Earthing up was carried out one month after sowing.

3.6.3 Harvesting

Harvesting of individual crop was done separately as and when the crops matured and yields were recorded.



CA + Finger millet (T_1)



Finger millet alone (T_8)



CA + Fodder maize (T_2)



Fodder maize alone (T_9)



CA + Field bean (T_3)



Field bean alone (T_{10})

Plate 3.2: Comparison of treatments under custard apple based agri–horticulture system



CA + Niger (T_4)



Niger alone (T_{11})



CA + Chilli (T_5)



Chilli alone (T_{12})



CA + Cowpea (T_6)



Cowpea alone (T_{13})

Plate 3.3: Comparison of treatments under custard apple based agri–horticulture system



CA + Foxtail millet (T_7)



Foxtail millet alone (T_{14})

Plate 3.4: Comparison of treatments under custard apple based agri–horticulture system

Name of the crop	Harvesting *kharif* 2017	Harvesting *kharif* 2018
Custard apple (*Annona squamosa* L.)	16–9–2017 5–10–2017 20–10–2017 12–11–2017	12–9–2018 30–9–2018 22–10–2018 16–11–2018
Finger millet *(Eleusine coracana* Gaertn.)	28–12–2017	15–12–2018
Fodder maize *(Zea mays* L.)	20–10–2017	13–10–2018
Field bean *(Dolichos purpureus* L.)	30–10–2017	30–10–2018
Niger *(Guizotia abyssinica* Cass.)	14–11–2017	10–11–2018
Chilli (*Capsicum annuam*)	16–11–2017 28–11–2017 10–12–2017 18–12–2017	11–11–2018 27–11–2018 13–12–2018 26–12–2018
Cowpea (*Vigna unguiculata* L.)	30–10–2017	30–10–2018
Foxtail millet (*Setaria italica)*	10–11–2017	16–11–2018

3.6.3.1 Custard apple

The custard apple was harvested during the months of September, October and November by selecting fully mature green fruits *i.e.* when the area between two segments has turned to cream colour and weight was recorded. Harvesting was done manually in the morning hours (8:00 to 9:00 am).

3.6.3.2 Assessment of efficiency of intercropping system

3.6.3.2.1 Custard apple equivalent yield

Custard apple equivalent yield (CEY) of intercropping system was calculated by the following formula and expressed in kg per hectare.

$$\text{CEY (kg ha}^{-1}) = \frac{\text{Intercrop yield (kg ha}^{-1}) \text{ X Price (Rs kg}^{-1})}{\text{Custard apple price (Rs kg}^{-1})}$$

3.6.3.2.2 Sustainable yield index

The sustainability yield index (SYI) was worked out by using the following formula given by Singh *et al*., 1990.

$$SYI = \frac{Y - \sigma}{Ymax}$$

Where,

Y = Estimated average yield of a practice across the year

σ = Estimated, standard deviation

Ymax =Maximum yield in the experiment during the year of cultivation

3.6.3.2.3 Land equivalent ratio

The land equivalent ratio (LER) was worked out by using the following formula given by Willey (1979).

$$LER = La + Lb = (Ya/Sa + Yb/Sb)$$

Where,

La and Lb = LER's for the crops 'a' and 'b'.

Ya and Yb = Individual crop yield under intercropping.

Sa and Sb = Individual crop yield under sole cropping.

3.6.3.2.4 Area time equivalent ratio

Area time equivalent ratio (ATER) was calculated by using the formula as suggested by Hiebsch and McCollam (1987).

$$ATER = \frac{(RYa \text{ X } tA) + (RYb \text{ X } tB)}{T}$$

Where,

RY = Relative yield of species A and B $\quad RY = \frac{\text{Yield of intercrop per ha}}{\text{Yield of sole crop per ha}}$

RYa and RYb = relative yields of crop 'a' and crop 'b' respectively.

tA and tB = Time duration of crop 'a' and crop 'b' respectively.

T = Total duration of intercropping system.

3.6.3.2.5 Rain water use efficiency

The total rainfall received during the crop growth period (July to November) was used to work out the rain water use efficiency (RWUE) as kg of custard apple equivalent yield fruits produced per ha–mm of rain water received (kg ha–mm^{-1}).

3.7 Plant Analysis

3.7.1 Collection and preparation of plant samples

Plant samples (both grain and straw) of field crops were collected from each plot, air dried and then kept for drying in hot–air oven at 60°C for 48 hours. The samples were then powdered using Wiley mill and prepared for analysis. Different plant parameters analyzed and methods adopted are listed in Table 3.3.

3.7.2 Total macro and micronutrients content of different crops

Plant samples were analyzed for total nutrient content at harvest as per standard protocols and expressed in percentage (for micronutrients, mg kg^{-1}). The total N content was estimated by Micro–Kjeldhal digestion–distillation method (Piper, 1966) and expressed in percentage. Diacid digestion of plant samples was carried out to extract other nutrients like P, K, Ca, Mg, S, Fe, Mn, Zn and Cu. The total P content was estimated by vanadomolybdo phosphoric yellow colour method using spectrophotometer at 420 nm of wavelength (Piper, 1966) and expressed in percentage. The total potassium was determined by flame photometry (Piper, 1966) and content was expressed in percentage.

Table 3.3: Methods adopted for extraction and analysis of plant samples for total nutrients content

Parameter	Method	Reference
Total Nitrogen (%)	Kjeldahl digestion and distillation	Piper (1966)
Total Phosphorus (%)	Diacid digestion and vanadomolybdate and spectrophotometry	Piper (1966)
Total Potassium (%)	Diacid digestion and Flame Photometry	Piper (1966)
Total Calcium (%)	Diacid digestion and Versenate titremetry	Jackson (1973)
Total Magnesium (%)	Diacid digestion and Versenate titremetry	Jackson (1973)
Total Sulphur (%)	Diacid digestion and Turbidometry	Jackson (1973)
Micronutrients Fe, Mn, Zn and Cu (mg kg^{-1})	Diacid digestion and atomic absorption spectrophotometry	Lindsay and Norvell (1978)

Total calcium and magnesium in plant samples were determined by Versenate method by titrating an aliquot of digested sample against standard EDTA solution using erichrome black T and patton reeders indicators (Jackson, 1973). Total sulphur content of plant sample was estimated by turbidometric method using spectrophtometer at 420nm of wavelength and expressed in percentage (Jackson, 1973). The Fe, Mn, Zn and Cu contents of plant samples were estimated in the diacid digested extract by atomic absorption spectrophotometer using appropriate hallow cathode lamp after calibration with standards (Lindsay and Norvell, 1978).

3.7.3 Nutrient uptake by crop

Nutrient uptake (kg ha^{-1}) by crop was calculated for each treatment separately using the following formula,

$$\text{Nutrient uptake (kg ha}^{-1}) = \frac{\text{Nutrient concentration (\%)}}{100} \text{ X Biomass (kg ha}^{-1})$$

3.8 Soil Analysis

Soil samples were collected at 0–15 cm depth from each plot at the time of sowing and after harvest of the crops and were prepared for analysis. The soil samples collected were subjected for analyzing physical, chemical and biological properties of the soil as per the objectives of the investigation and the details of methodologies (Table 3.4) followed are briefly described below.

3.8.1 Physical properties of soil

3.8.1.1 Particle size distribution

Particle size distribution in soil was determined by following International pipette method (Piper, 1966). Air dry soil (< 2 mm) was treated overnight with hydrogen peroxide to remove organic matter. The treated soil was dispersed by using sodium hexametaphosphate. The dispersed solution was passed through > 0.05 mm mesh sieve to separate sand particles. The suspension obtained after sieving was analysed for silt and clay by using international pipette method.

Table 3.4: Methods followed for analysis of physical, chemical and biological properties of soil

Parameter	Method	Reference
Physical properties		
Particle size distribution	International pipette method	Piper (1966)
Bulk density (Mg m^{-3})	Core sampler method	Piper (1966)
MWHC (%)	Keen Raczkowski Cup method	Piper (1966)
Infiltration rate (cm hr^{-1})	Double ring infiltrometer method	Bouwer (1986)
Aggregate stability	Yoder's apparatus method	Van Bavel (1949)
Chemical properties		
pH (1:2.5)	Potentiometry method	Jackson (1973)
EC (dS m^{-1})	Conductometry method	Jackson (1973)
CEC [cmol (p^+) kg^{-1}]	Ammonium acetate leaching method	Jackson (1973)
Organic carbon (g kg^{-1})	Wet oxidation method	Walkley and Black (1934)
Avail. N (mg kg^{-1})	Alkaline potassium permanganate method	Subbaiah and Asija (1956)
Avail. P_2O_5 (mg kg^{-1})	Bray's extraction method and spectrophotometry	Jackson (1973)
Avail. K_2O (mg kg^{-1})	*N* NH_4OAC extraction method and Flame photometry	Jackson (1973)
Exch. Ca [cmol (p^+) kg^{-1}]	*N* NH_4OAC extraction method and Versenate titrimetry	Jackson (1973)
Exch. Mg [cmol (p^+) kg^{-1}]	*N* NH_4OAC extraction method and Versenate titrimetry	Jackson (1973)
Avail. S (mg kg^{-1})	$CaCl_2$ extraction method and Turbidimetry	Black (1965)
DTPA extractable Fe, Mn, Zn and Cu (mg kg^{-1})	DTPA extraction method and Atomic absorption spectrophotometry	Lindsay and Norvell (1978)
Biological properties		
Dehydrogenase activity	2, 3, 5–Triphenyl tetrazolium chloride (TTC) reduced to triphenyl formazone (TPF)	Casida *et al*. (1964)
Urease activity	Tris (hydroxymethyl) amino methane (THAM) buffer	Tabatabai and Bremner (1972)
Phosphatase (acid and alkaline) activity	p-nitrophenol phosphate (PNP-P) was used as a substrate and the hydrolyzed p-nitrophenol (PNP) was measured	Tabatabai and Bremner (1969)
Microbial biomass carbon (MBC)	Fumigation and extraction method	Carter (1991)
Microbial biomass nitrogen (MBN)		
Microbial biomass phosphorus (MBP)		Brookes *et al.* (1982)

3.8.1.2 Infiltration rate

Infiltration measurements were made by using double ring infiltrometer. Inner cylinder from which the infiltration measurements were taken was 30 cm in diameter. The outer cylinder which was used to form the buffer pond was about 60 cm in diameter. The cylinders were installed about 15 cm deep in soil. Known volume of water is added to the inner cylinder. The time intervals were noted through a stop watch. The outer cylinder or a buffer zone was filled with water immediately after filling the inner cylinder in such a way that water levels in the inner cylinder and the outer cylinder were kept approximately same. Cumulative infiltration rate I is plotted as function of elapsed time (Bouwer, 1986).

3.8.1.3 Bulk density

Bulk density of soil samples were determined by core sampler method (Black, 1965) recording the fresh weight in the field and dry weight in the laboratory. Drying of soil was done in hot air oven to constant weight. Bulk density was calculated as dry weight of soil per unit volume of the cylindrical core used to sample the soil in the field.

3.8.1.4 Aggregate stability

Large clods were broken by hand into smaller segments along natural cleavage prior to air–drying of the soil and they were used to study the aggregate stability by wet sieving technique by using yoder apparatus. After wet–sieving, aggregates from each sieve were transferred to a set of pre–weighed beakers, oven–dried at 60°C until water evaporated and then weighed. The mean weight diameter (MWD) was calculated as an index of aggregation (Black, 1965) using the following formula:

$$MWD=\sum xi\ wi$$

Where, wi is the proportion of each aggregate class in relation to whole, and xi is the mean diameter of the class (mm).

3.8.1.5 Maximum water holding capacity

The maximum water holding capacity (MWHC) of soil was determined by adopting Keen–Raczkowski cup method (Piper, 1966). The soil in the keen's cup was saturated using the capillary fringe. After the saturation weight was measured and was kept in hot air oven for drying at 105°C. The differences in the weights of saturated and oven dried soils were used in estimating MWHC of soil.

3.8.2 Chemical properties of soil

3.8.2.1 Soil reaction

The soil pH was determined in soil–water suspension (1:2.5 ratio) through glass electrode by using digital pH meter (Systronics model 362) (Jackson, 1973).

3.8.2.2 Electrical conductivity

Electrical conductivity (EC) in supernatant liquid of 1:2.5 soil–water suspension was determined by using conductivity bridge (Digital conductivity bridge, Systronics 308) (Jackson, 1973).

3.8.2.3 Organic carbon

Soil organic carbon content of soil was determined through wet oxidation method outlined by Walkley and Black (Jackson, 1973) and content was expressed in gram per kg of soil.

3.8.2.4 Cation exchange capacity

The cation exchange capacity (CEC) of soil was determined by adopting ammonium acetate leaching method (Jackson, 1973) and expressed in cmol (p^+) kg^{-1} of soil.

3.8.2.5 Determination available nutrient content of soil

Soil samples were collected at 0–15 cm depth of soil from experimental field and subjected for available nutrient analysis as per the standard procedures.

3.8.2.5.1 Available nitrogen

Available nitrogen content of soil was estimated by alkaline permanganate method of Subbiah and Asija (1956) and expressed in milligram per kg of soil.

3.8.2.5.2 Available phosphorus

Available phosphorus in soil was extracted using Brays extractant and a suitable aliquot was pipetted out for development of blue colour. The intensity of blue colour was estimated through spectrophotometer at 660 nm wavelength (Jackson, 1973) and expressed in milligram per kg of soil.

3.8.2.5.3 Available potassium

Available potassium in soil was analyzed through flame photometer from the extract of neutral normal ammonium acetate (Jackson, 1973) and expressed in milligram per kg of soil.

3.8.2.5.4 Exchangeable calcium and magnesium

The exchangeable calcium and magnesium in soil were estimated by versenate titration method by titrating an aliquot of extracted sample against standard EDTA solution using erichrome black T and patton reeders indicators (Jackson, 1973).

3.8.2.5.5 Available sulphur

Sulphur content in the soil was extracted through $CaCl_2$ and content was estimated by turbidometric method using spectrophotometer at 420 nm of wavelength (Black, 1965).

3.8.2.5.6 DTPA extractable Fe Mn, Zn and Cu

The extracting solution used for this purpose consisted of 0.005*M* DTPA (Diethylene Triamine Penta Acetic acid), 0.01*M* $CaCl_2$ and 0.1*M* TEA (Tri Ethanol Amine) buffered at pH 7.3 (Lindsay and Norwell, 1978). The concentration of Fe, Zn, Mn and Cu was determined using atomic absorption spectrophotometer (Perkin Elmer Analyst 700 model) using appropriate hallow cathode lamps.

3.8.3 Biological Properties of soil

3.8.3.1 Dehydrogenase activity

Dehydrogenase activity was determination by adopting the methodology given by Casida *et al.* (1964). The principle here is that 2,3,5–triphenyl tetrazolium chloride (TTC), used as electron acceptor in place of O_2, is reduced to triphenyl formazon (TPF), which imparts colour. The amount of TPF formed was measured using spectrophotometer at 485 nm of wavelength and expressed as µg of TPF formed g^{-1} soil day^{-1}.

3.8.3.2 Urease activity

Determintion of urease activity was carried out by adopting the procedure given by Tabatabai and Bremner (1972). It involves the determination of ammonia released by urease acivity when soil is incubated with tris (hydroxymethyl) amino methane (THAM) buffer, urea solution and toluene at 37°C for 2 hours. Ammonia released was determined by a rapid procedure involving extracting the incubated soil sample with 2.5*M* KCL containing a urease inhibitor (Ag_2SO_4).

3.8.3.3 Phosphatase activity

The phosphatase activity was determined by adopting the procedure given by Tabatabai and Bremner (1969). In this method, *p*–nitrophenol phosphate (PNP–P) was used as a substrate and the hydrolyzed p–nitrophenol (PNP) was measured. The produced PNP in the soil was extracted and quantified to assess the phosphatase activity. The activity was expressed as µg of PNP g^{-1} soil h^{-1} at 37 ± 20°C.

3.8.3.4 Soil microbial biomass C and N

Soil microbial biomass carbon and nitrogen were estimated using fumigation and extraction method as proposed by Carter (1991). It involves the determination of ninhydrin–reactive N released during the fumigation of soil using ninhydrin reagent and used as a measure of microbial biomass. The procedure involves, each soil sample was divided in to two sets. One set of soil sample (10 g soil on oven dry basis) was fumigated using ethanol–free chloroform in screw–capped bottles for 5 days. Then the screw caps were removed and bottles were kept in an oven at 40°C for 24 hours to remove the chloroform. It was then extracted using 2*M* KCl by placing the bottles on a reciprocal shaker for 30 minutes. The suspension was filtered using Whatman No.1 filter paper. Another set of unfumigated soil sample was also extracted in a similar manner. To a known aliquot of soil exract, 4 mL of freshly prepared ninhydrin reagent was added and the mixture was boiled in water bath for 20 minutes till the development of purple colour. The contents were allowed to cool and the volume was made up to 10 ml using 1:1 mixture of methoxy ethanol and distilled water. The intensity of purple colour developed was recorded using spectrophotometer at 570 nm wave length. A standard curve was prepared using graded concentration of L–Leucine –N (3.5 to 16.8 µg N/mL) dissolved in 2*M* KCl. Absorbance values were compared with a standard curve and the microbial biomass C and N were calculated using the formula.

$$\text{Biomass C g soil}^{-1} = \frac{\text{Ninhydrin reactive–N in fumigated soil} - \text{Ninhydrin reactive–N in unfumigated soil}}{\text{Weight of soil sample}} \text{ X } 24$$

$$\text{Biomass N g soil}^{-1} = \frac{\text{Ninhydrin reactive–N in fumigated soil} - \text{Ninhydrin reactive–N in unfumigated soil}}{\text{Weight of soil sample}} \text{ X } 2.8$$

3.8.3.5 Soil microbial biomass P

For the determination of soil microbial biomass phosphorus (MBP), 10 gram soil sample (oven dry basis) was shaken with 200 mL 0.5 *M* $NaHCO_3$ in 250 mL conical flasks for 30 minutes at 25°C and 150 rpm in an orbital shaker (Brookes *et al.,* 1982).

MBP was determined in both fumigated and non–fumigated soil samples under similar set of conditions and values were measured at 660 nm wavelength using ascorbic acid method (Olsen *et al.,* 1954).

3.8.4 Carbon and nitrogen dynamics

To study the carbon and nitrogen dynamics, different fractions of carbon and nitrogen in the soil were analyzed. Soil samples were collected from each treatment after the harvest of crops at four different depths *i.e.,* 0–15, 15–30, 30–60 and 60–90 cm. These samples were processed and subjected for analysis with respect to different fractions of carbon and nitrogen following standard procedures as follows.

3.8.4.1 Carbon dynamics

To study the carbon dynamics in soil, soil samples were analyzed for different carbon fractions like soil organic carbon, soil inorganic carbon, water soluble carbon, active carbon, microbial carbon and labile carbon following standard procedures mentioned as follows.

3.8.4.1.1 Soil organic carbon

Organic carbon (OC) content of soil was estimated according to Walkley and Black's wet oxidation method (Jackson, 1973) and expressed in gram per kg of soil.

3.8.4.1.2 Soil inorganic carbon

Calcium carbonate is the major component of soil inorganic carbon. Acid neutralization method or rapid titration method of Piper (1944) was used for estimation of soil inorganic carbon content. 10 g soil was extracted with standard HCl and stirred intermittently for one hour and allowed to settle. 10 mL of supernatant aliquot was titrated against standard NaOH using bromothymol blue indicator. The values were noted down and amount inorganic carbon was calculated with standard formula.

3.8.4.1.3 Water soluble carbon

The water soluble carbon content of soil was estimated using the method described by McGill *et al.* (1986). It was determined by mixing 10 g of soil with 20 mL distilled water and shaken for one hour. This was followed by centrifugation for 5 minutes at 6000 rpm, filtration and titrimetric determination.

3.8.4.1.4 Active/labile carbon

The active carbon content of soil was determined by modified method of Blair *et al.* (1995) as outlined by Weil *et al.* (2003). 5 g air dried sol sample taken in 20 mL of 0.02 *M* $KMnO_4$ and shaken for 2 minutes, followed by centrifugation to get clear supernatant and measuring the light absorbance at 550 nm of wavelength using colorimeter/spectrophotometer.

3.8.4.1.5 Microbial carbon

Soil microbial carbon was estimated following the fumigation and extraction method as proposed by Carter (1991) as mentioned in Section 3.8.3.4.

3.8.4.1.6 Total carbon

Total carbon in soil was estimated by adding both organic and inorganic carbon.

3.8.4.2 Nitrogen dynamics

To study the nitrogen dynamics in soil, soil samples were subjected for analysis for different fractions of nitrogen following standard procedures as follows.

3.8.4.2.1 Total nitrogen

Total nitrogen content of soil was estimated by following Micro–Kjeldahl method. The soil samples were digested with concentrated sulphuric acid and then contents were distilled with excess of 40 per cent NaOH. Ammonia liberated during distillation was trapped in 4 per cent boric acid containing mixed indicator. Total nitrogen content was determined by titration against standard sulphuric acid (McKenzie and Wallace, 1954).

3.8.4.2.2 Available nitrogen

Available nitrogen content of soil was determined by alkaline permanganate method outlined by Subbiah and Asija (1956).

3.8.4.2.3 Ammonical (NH_4–N) and nitrate (NO_3–N) nitrogen

Ammonical and nitrate Nitrogen fraction were determined by following the procedure as outlined by Black (1965). 3 g of soil was shaken with 30 mL of 2*N* KCl for 1 hour and filtered. The extract was then stored in refrigerator for further use. Contents of NH_4–N and NO_3–N were extracted using Kjeldahl distillation process with MgO and Devarda's alloy, respectively.

3.9 Statistical analysis and interpretation of data

The data collected from the experimental field were analysed statistically following the procedure described by Panse and Sukhatme (1967). The level of significance used in 'F' and 't' test was *P=0.05*. Critical differences were calculated using 't' test wherever 'F' test was significant.

IV RESULTS AND DISCUSSION

Climate change induced rainfall aberrations and soil degradation with rapid burning of soil organic resources emphasizes for alternative resilient technologies. Cropping system based approach with horticulture/forestry component essentially sustain soil quality and livelihood under dryland. Monitoring carbon and nitrogen dynamics are necessitated in the agri–horti system to assess climate resilience. The present study was carried out at All India Coordinated Research Project for Dryland Agriculture (AICRPDA), UAS, GKVK, Bangalore, in an ongoing experiment "Evaluation of custard apple based agri-horti system involving cereals and pulses" which was started in *Kharif* 2012 in a custard apple orchard (planted in 2009) and various intercrops were sown during *Kharif* and left fallow during summer. The present experiment entitled **"Carbon and nitrogen dynamics under agri–horticulture system"** was carried out during *Kharif* seasons of 2017 and 2018 and the results are presented and discussed in this chapter under different headings.

4.1 Effect of custard apple based agri–horticulture system on soil physical properties

4.1.1 Effect of custard apple based agri–horticulture system on soil texture

Soil texture is an important attribute in regulating the soil organic matter accumulation and its turnover. It is more or less permanent property of soil which cannot be changed easily. This is an essential prerequisite for the isolation of management effects on soil physical properties, since interferences from textural differences could safely be ignored (Schjonning *et al.,* 1994). In the present experiment, the content of sand, silt and clay did not vary significantly among the treatments and textural class was found to be sandy clay loam (Table 4.1). But the texture ranged from 62.48% to 57.37% sand, 14.62% to 12.41% silt and 28.74% to 24.22% clay.

4.1.2 Effect of custard apple based agri–horticulture system on bulk density of soil

The data on bulk density of soil as influenced by custard apple based agri–horticulture system are presented in Table 4.1.

Table 4.1: Soil texture and bulk density as influenced by custard apple based agri–horticulture system

Treatments	Soil texture			Bulk density (Mg m^{-3})			
	Sand (%)	Silt (%)	Clay (%)	Soil depth (cm)			
				0-15	15-30	30-60	60-90
T_1: CA + Finger millet	60.53	13.35	26.12	1.44	1.46	1.51	1.54
T_2: CA + Fodder maize	62.48	12.77	24.75	1.49	1.50	1.51	1.54
T_3: CA + Field bean	59.16	12.41	28.43	1.38	1.44	1.50	1.53
T_4: CA + Niger	60.10	13.72	26.18	1.45	1.48	1.50	1.54
T_5: CA + Chilli	61.29	12.84	25.87	1.43	1.45	1.51	1.53
T_6: CA + Cowpea	57.37	13.89	28.74	1.38	1.44	1.49	1.53
T_7: CA + Foxtail millet	61.57	13.07	25.35	1.44	1.48	1.50	1.54
T_8: Finger millet alone	61.46	12.89	25.65	1.44	1.47	1.50	1.55
T_9: Fodder maize alone	62.12	13.66	24.22	1.50	1.49	1.52	1.54
T_{10}: Field bean alone	59.88	14.09	26.03	1.39	1.45	1.49	1.54
T_{11}: Niger alone	60.37	13.31	26.32	1.44	1.45	1.49	1.53
T_{12}: Chilli alone	61.63	13.27	25.10	1.43	1.47	1.50	1.54
T_{13}: Cowpea alone	59.54	14.62	25.84	1.40	1.45	1.49	1.55
T_{14}: Foxtail millet alone	61.84	12.98	25.18	1.45	1.48	1.50	1.54
T_{15}: Custard apple alone	61.82	13.59	24.59	1.55	1.53	1.51	1.54
S.Em ±	**2.95**	**0.65**	**1.25**	**0.02**	**0.02**	**0.07**	**0.07**
CD @ 5 %	**NS**	**NS**	**NS**	**0.06**	**0.05**	**NS**	**NS**

Note: CA–Custard apple

NS–Non significant

Bulk density at 0–15 cm depth of soil differed significantly under custard apple based agri–horticulture system. CA + cowpea (T_6) recorded significantly lower bulk density (1.38 Mg m^{-3}) followed by CA + field bean (T_3) (1.38 Mg m^{-3}) and Cowpea alone (T_{13}) (1.40 Mg m^{-3}) compared to Fodder maize alone (1.50 Mg m^{-3}), CA + Foxtail millet (1.44 Mg m^{-3}), CA + Finger millet (1.44 Mg m^{-3}), CA + Niger (1.45 Mg m^{-3}) and CA + Fodder maize (1.49 Mg m^{-3}). Intercropping systems recorded lower bulk density than their respective sole crops especially in the treatments with legume crops might be attributed to increase in soil organic matter content (Maheswarappa *et al.*, 1998) brought about by the incorporation of the huge amount of biomass of the intercrops, which resulted in better aggregation properties of the soil. Swain and Patro (2007) also reported a decrease in bulk density of soil while studying the effects of different intercropping in mango orchards. Many studies have showed that the decomposition products of organic materials would usually help in granulation of soil particles and thus increase the porosity of the soil; which in turn could have lowered bulk density of the soil (Bhardwaj *et al.*, 1994). Significantly higher bulk density (1.55 Mg m^{-3}) was noticed in custard apple alone (T_{15}) treatment. Higher bulk density under custard apple alone (T_{15}) might be due to relatively non–disturbance of soil. These results are in accordance with findings of Fabien Ferchaud *et al.* (2016) who reported that the bulk density in the 0–40 cm layer was higher for perennial than annual crops, due to soil compaction occurring during the harvest of perennial crops (particularly for late harvest) and absence of soil tillage.

Irrespective of treatments, surface layer (0 to 15 cm) recorded significantly lower bulk density as compared to subsurface layers. Bulk density at 15–30 cm soil depth significantly differed due to custard apple based agri–horticulture system. CA + Cowpea (T_6) recorded significantly lower bulk density (1.44 Mg m^{-3}) followed by CA + Field bean (1.44 Mg m^{-3}) and cowpea alone (1.45 Mg m^{-3}) compared to CA + Foxtail millet (1.48 Mg m^{-3}), CA + Fodder maize (1.50 Mg m^{-3}) , Finger millet alone (1.47 Mg m^{-3}), CA + Finger millet (1.46 Mg m^{-3}) and CA + Niger (1.48 Mg m^{-3}). Significantly higher bulk density (1.53 Mg m^{-3}) was noticed under custard apple alone (T_{15}).

Bulk density at 30–60 and 60–90 cm soil depth did not differ significantly due to custard apple based agri–horticulture system. Generally, irrespective of treatments bulk

density increased with increase in depth of soil which might be due to low organic matter content of lower layers and compaction from the pressure of the upper layers. Similar findings were also reported by Patil and Jagdish Prasad (2004) and Gurumurthy *et al.* (2009).

4.1.3 Effect of custard apple based agri–horticulture system on aggregate stability and mean weight diameter of soil

The data pertaining to the effect of custard apple based agri–horticulture system on aggregate stability and mean weight diameter (MWD) of soil is presented in Table 4.2 and it was varied significantly among the treatments.

Higher aggregate stability and MWD (64.51% and 1.93 mm, respectively) were noticed in treatment CA + Cowpea (T_6) followed by Cowpea alone (T_{13}) (63.73% and 1.87 mm, respectively) and T_3 (CA + Field bean) (63.32% and 1.91 mm, respectively). Higher soil aggregate stability under these treatments might be due to the positive effect of legume crops (Cowpea and field bean) on soil properties through large addition of crop residues to soil especially under intercropping systems where organic matter addition to soil from both crops. These findings are in accordance with some scientists who reported that legume crops have a potential to improve physical properties of soil by being a soil conditioner and improving the physical properties (Srinivasarao *et al.,* 2012). Leguminous cover crops have a positive effect on soil physical properties mainly due to the production capacity of huge biomass which provides substrata for soil biological activity and SOM (Lal, 2011). Legumes also affect soil structure by their influence on aggregation (Mousavi *et al.,* 2009).

The treatments T_1 (CA + Finger millet) (58.24% and 1.82 mm, respectively) and T_7 (CA + Foxtail millet) (57.24% and 1.76 mm, respectively) had higher aggregate stability and MWD than T_4 (CA + Niger) (56.75% and 1.74 mm, respectively), T_5 (CA + Chilli) (55.19% and 1.73 mm, respectively), T_{11} (Niger alone) (55.43% and 1.70 mm, respectively) and T_{14} (Foxtail millet alone) (55.77% and 1.72 mm, respectively) but the difference was non–significant.

Significantly lower aggregate stability was noticed in treatment T_9 (Fodder maize alone) (49.36%) however this was on par with treatments T_{15} (Custard apple alone) (50.36%) and T_2 (CA + Fodder maize) (50.54%). Significantly lower aggregate stability and MWD (49.36% and 1.50 mm, respectively) were noticed in treatment T_9 (Fodder maize alone) might be due to lower addition of crop residues and organic matter to soil resulted in lower aggregation of soil, since soil aggregation is positively correlated with organic matter content of soil. With respective crops, aggregate stability values were higher under intercropping systems than sole crops but the difference was non–significant. Many authors have reported that the regular addition of organic matter through compost and root biomass to soil induce the formation of macroaggregates as they are the C source for microbial activities and the production of microbial–derived binding agents (Hatti *et al.,* 2008; Benbi and Senapati, 2010; Chen *et al.,* 2010). It was also reported that stabilization is favoured through the binding action of humic substances, polysaccharides and fungal hyphae (Graham *et al.,* 2002).

4.1.4 Effect of custard apple based agri–horticulture system on maximum water holding capacity of soil

The data on maximum water holding capacity (MWHC) of soil as influenced by custard apple based agri–horticulture system is presented in Table 4.2. The water–holding capacity of soil influences the availability of nutrients to the plants and promotes the root activities. The MWHC of soil is mainly dependent on the soil organic matter, porosity, soil aggregation, bulk density etc., which varied among the treatments significantly in the present experiment.

Among the different treatments, CA + cowpea (T_6) treatment recorded significantly higher MWHC (41.53%) followed by Cowpea alone (T_{13}) (40.26%), CA + Field bean (T_3) (39.66%) and Field bean alone (T_{10}) (39.17%). This was due to increase in soil organic matter content and better soil aggregation in these treatments. Higher organic carbon under these treatments was mainly contributed by leaf litter, root and crop residue decomposition coupled with lower loss of soil carbon which resulted in higher MWHC. These results are in agreement with Rai *et al*. (2009) and Srinivasan *et al.*

(2010). It is a well–known fact that the water retention capacity of a soil is directly related to its porosity and indirectly related to its bulk density. An increase in organic carbon and concomitant increase in the non–capillary porosity of the soil brought about by favourable interaction of clay and humus and soil aggregation could lead to overall increase in MWHC of the soil. The greater MWHC of different intercropping systems were attributed to incorporation of crop residues into the soil, which helped to conserve soil moisture and reduce evaporation losses due to structural improvement (Ramulu, 2014).

The treatments T_4 (CA + Niger) (33.45%), T_5 (CA + Chilli) (34.88%) and T_7 (CA + Foxtail millet) (35.27%) were found to be on par with each other. MWHC was significantly lower in custard apple alone (T_{15}) (33.19%) followed by CA + Fodder maize (T_2) (34.31%) and Fodder maize alone (T_9) (35.29%). Relatively lower MWHC in custard apple alone and fodder maize treatments might be due to lower organic matter content, low aggregate stability and higher bulk density. The addition and recycling of biomass under intercropping systems improves organic C, soil structure and soil aeration, thereby improving the physical, chemical, and biological environments of soil (Maheswarappa *et al.,* 1998), which might be responsible for increased MWHC of soil under intercropping systems compared to sole crops of specific crops but the difference was non–significant.

4.1.5 Effect of custard apple based agri–horticulture system on infiltration rate of soil

Custard apple based agri–horticulture system significantly influenced the infiltration rate of soil and the data are presented in Table 4.2. Significantly higher infiltration rate was recorded in treatment CA + Cowpea (T_6) (24.99 cm hr^{-1}). Improved organic matter content and soil aggregate stability facilitated water infiltration. Although there is little research on the interactions of SOM and infiltration, Franzluebbers (2002) reported that greater SOM increased the infiltration rate by up to 27 per cent on sandy loam soils in a humid subtropical climate. However, this was followed by CA + Field bean (T_3) (24.37 cm hr^{-1}), Cowpea alone (T_{13}) (20.67 cm hr^{-1}) and Field bean alone (T_{10})

Table 4.2: Aggregate stability, mean weight diameter, MWHC and infiltration rate of soil as influenced by custard apple based agri–horticulture system

Treatments	Aggregate stability (%)	Mean weight diameter (mm)	MWHC (%)	Infiltration rate (cm hr^{-1})
T_1: CA + Finger millet	58.24	1.82	36.49	19.71
T_2: CA + Fodder maize	50.54	1.54	34.31	16.83
T_3: CA + Field bean	63.32	1.91	39.66	24.37
T_4: CA + Niger	56.75	1.74	33.45	17.54
T_5: CA + Chilli	55.19	1.73	34.88	16.36
T_6: CA + Cowpea	64.51	1.93	41.53	24.99
T_7: CA + Foxtail millet	57.24	1.76	35.27	17.84
T_8: Finger millet alone	56.23	1.77	36.46	17.63
T_9: Fodder maize alone	49.36	1.50	35.29	15.78
T_{10}: Field bean alone	62.71	1.87	39.17	20.81
T_{11}: Niger alone	55.43	1.70	34.35	15.27
T_{12}: Chilli alone	55.26	1.69	36.51	15.09
T_{13}: Cowpea alone	63.73	1.87	40.26	20.67
T_{14}: Foxtail millet alone	55.77	1.72	35.31	14.11
T_{15}: Custard apple alone	50.36	1.74	33.19	12.36
S.Em ±	**2.73**	**0.08**	**1.35**	**0.86**
CD @ 5 %	**7.91**	**0.25**	**3.90**	**2.49**

Note: CA–Custard apple

(20.81 cm hr^{-1}). It is also said that legume crops frequently result in better infiltration of water, due to direct effects of the crop residue in soil formation and aggregation (Mousavi *et al.,* 2009).

However, the infiltration rate was non–significant among the treatments T_1 (CA + Finger millet) (19.71 cm hr^{-1}), T_4 (CA + Niger) (17.54 cm hr^{-1}), T_7 (CA + Foxtail millet) (17.84 cm hr^{-1}) and T_8 (Finger millet alone) (17.63 cm hr^{-1}). Significantly lower infiltration rate was noticed in treatment T_{15} (Custard apple alone) (12.36 cm hr^{-1}) followed by T_{14} (Foxtail millet alone) (14.11 cm hr^{-1}) and T_{12} (Chilli alone) (15.09 cm hr^{-1}). Lower infiltration rate under custard apple alone might be due to lower organic carbon content, lesser degree of soil aggregation coupled with higher bulk density.

4.2 Effect of custard apple based agri–horticulture system on soil chemical properties before sowing of crops during 2017 and 2018

4.2.1 Soil pH, electrical conductivity, organic carbon content and cation exchange capacity of soil

The data pertaining to soil pH, electrical conductivity (EC) and organic carbon content under custard apple based agri–horticulture system is presented in Table 4.3. Agroforestry systems increased soil organic carbon with the consequent increase of soil biological fertility by improving physical, chemical and biological properties of soil (Korwar *et al.,* 2006). The deep root system of fruit crops and addition of continuous leaf litter to the soil by tree help in providing vertical drainage and incorporation of biomass for continuous improvement in physical, chemical and biological soil properties (Avinash Chandra Rathore *et al.,* 2013).

Custard apple based agri–horticulture system significantly influenced the organic carbon content of soil but the effect on soil pH and EC was non–significant before sowing of the crops during 2017 and 2018 as well as in pooled data. However, in pooled data the soil pH ranged from 5.42 in CA + Cowpea (T_6) to 5.53 in CA + Foxtail millet (T_7) whereas, EC ranged from 0.04 dS m^{-1} in CA + Fodder maize to 0.06 dS m^{-1} in Custard apple alone treatments.

Table 4.3: Soil pH, electrical conductivity (EC), organic carbon and cation exchange capacity (CEC) of soil as influenced by custard apple based agri–horticulture system before sowing of crops during 2017 and 2018

Treatments	Soil pH			EC (dS m^{-1})			Organic carbon (g kg^{-1})			CEC [cmol (p+) kg^{-1}]
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	
T_1: CA + Finger millet	5.51	5.50	5.51	0.05	0.06	0.06	5.72	5.75	5.74	6.19
T_2: CA + Fodder maize	5.48	5.44	5.46	0.04	0.04	0.04	5.05	5.06	5.06	5.42
T_3: CA + Field bean	5.45	5.44	5.44	0.06	0.06	0.06	6.44	6.46	6.45	6.58
T_4: CA + Niger	5.49	5.49	5.49	0.05	0.05	0.05	5.47	5.44	5.46	5.65
T_5: CA + Chilli	5.50	5.51	5.51	0.06	0.05	0.06	5.53	5.57	5.55	5.71
T_6: CA + Cowpea	5.43	5.40	5.42	0.05	0.05	0.05	6.54	6.54	6.54	6.61
T_7: CA + Foxtail millet	5.53	5.52	5.53	0.06	0.06	0.06	5.31	5.36	5.33	6.05
T_8: Finger millet alone	5.49	5.50	5.50	0.06	0.05	0.06	5.55	5.53	5.54	6.11
T_9: Fodder maize alone	5.47	5.45	5.46	0.05	0.06	0.05	4.83	4.83	4.83	5.38
T_{10}: Field bean alone	5.45	5.44	5.45	0.05	0.05	0.05	6.16	6.17	6.17	6.41
T_{11}: Niger alone	5.48	5.49	5.49	0.06	0.05	0.06	5.13	5.18	5.16	5.53
T_{12}: Chilli alone	5.49	5.47	5.48	0.07	0.04	0.06	5.37	5.41	5.39	5.61
T_{13}: Cowpea alone	5.46	5.45	5.46	0.06	0.05	0.06	6.28	6.30	6.29	6.42
T_{14}: Foxtail millet alone	5.49	5.46	5.47	0.05	0.05	0.05	5.16	5.18	5.17	5.60
T_{15}: Custard apple alone	5.53	5.51	5.52	0.07	0.06	0.06	5.14	5.17	5.16	5.40
S.Em ±	**0.05**	**0.25**	**0.13**	**0.01**	**0.01**	**0.01**	**0.27**	**0.27**	**0.27**	**0.28**
CD @ 5 %	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**0.78**	**0.78**	**0.78**	**0.82**

Note: CA–Custard apple
NS–Non significant

The custard apple based agri–horticulture system significantly influenced the organic carbon content of soil. Significantly higher organic carbon content was recorded in CA + Cowpea (T_6) (6.54 and 6.54 g kg^{-1}) treatment which was on par with CA + Field bean (T_3) (6.44 and 6.46 g kg^{-1}), Cowpea alone (T_{13}) (6.28 and 6.30 g kg^{-1}) and Field bean alone (T_{10}) (6.16 and 6.17 g kg^{-1}) during 2017 and 2018, respectively. Significantly lower organic carbon content was found in Fodder maize alone (4.83 and 4.83 g kg^{-1}) and CA + Fodder maize (5.05 and 5.06 g kg^{-1}) during 2017 and 2018, respectively.

Pooled analysis of 2017 and 2018 experimental data showed that significantly higher organic carbon was maintained under treatment CA + Cowpea (T_6) (6.54 g kg^{-1}) followed by CA + Field bean (T_3) (6.45 g kg^{-1}), Cowpea alone (T_{13}) (6.29 g kg^{-1}) and Field bean alone (T_{10}) (6.17 g kg^{-1}). The increased organic carbon content of soil in these intercropping systems might be attributed to decomposition of biomass of leguminous crops as well as leaf litter fall from custard apple. Similar findings on increase in organic carbon contents of orchard soil under intercropping practices in mango orchard have been reported by Nath *et al.* (2003) and Swain and Patro (2007).

However, the organic carbon was non–significant among T_1 (CA + Finger millet) (5.74 g kg^{-1}), T_4 (CA + Niger) (5.46 g kg^{-1}), T_5 (CA + Chilli) (5.55 g kg^{-1}), T_7 (CA + Foxtail millet) (5.33 g kg^{-1}), T_8 (Finger millet alone) (5.54 g kg^{-1}) and T_{12} (Chilli alone) (5.39 g kg^{-1}). Significantly lower organic carbon was found in treatment T_9 (Fodder maize alone) (4.83 g kg^{-1}) followed by T_{14} (Foxtail millet alone) (5.17 g kg^{-1}) and T_2 (CA + Fodder maize) (5.06 g kg^{-1}). Significantly lower organic carbon content in fodder maize might be attributed to lower addition of crop residues to soil, since this was used for fodder purpose. Due to higher addition of crop residues both from main crop and intercrop, better soil and moisture conservation and less oxidation of organic matter due to higher vegetative cover, the intercropping systems recorded higher organic carbon content than their respective sole cropping systems. Similar results were also reported by Das *et al*. (2011) and Ramulu (2014). The enrichment in organic carbon content under tree -based systems could be due to several factors such as contribution by litter fall, root biomass and root exudates (Sharma *et al.,* 2009).

Soil cation exchange capacity (CEC) varied significantly among the treatments due to custard apple based agri–horticulture system and the data are presented in Table 4.3. Significantly higher CEC was recorded under CA + Cowpea (T_6) (6.61 cmol (p^+) kg^{-1}) treatment followed by CA + Field bean (T_3) (6.58 cmol (p^+) kg^{-1}), Cowpea alone (T_{13}) (6.42 cmol (p^+) kg^{-1}) and Field bean alone (T_{10}) (6.41 cmol (p^+) kg^{-1}). Higher CEC under legume crops might be attributed to addition of crop residues, custard apple leaf litter and FYM as well as higher clay content in soil, which might lead to higher soil carbon stock and CEC due to larger surface area from both clay as well as organic matter content. Moreover, small sized particle (clay + organic matter) with higher number of exchange sites present in both clays and organic matter in soil might have contributed to higher CEC. Similar findings of increased CEC with higher organic matter in soil were also reported by Sharma *et al.* (2009) and Pellegrino *et al.* (2011).

Significantly lower or CEC was found in treatment T_9 (Fodder maize alone) (5.38 cmol (p^+) kg^{-1}) followed by T_{15} (Custard apple alone) (5.40 cmol (p^+) kg^{-1}) and T_2 (CA + Fodder maize) (5.42 cmol (p^+) kg^{-1}). However, the CEC was non–significant among T_1 (CA + Finger millet) (6.19 cmol (p^+) kg^{-1}), T_4 (CA + Niger) (5.65 cmol (p^+) kg^{-1}), T_5 (CA + Chilli) (5.71 cmol (p^+) kg^{-1}), T_7 (CA + Foxtail millet) (6.05 cmol (p^+) kg^{-1}), T_8 (Finger millet alone) (6.11 cmol (p^+) kg^{-1}) and T_{12} (Chilli alone) (5.61 cmol (p^+) kg^{-1}). Significantly lower CEC under fodder maize and custard apple alone treatments might be attributed to lower organic carbon and low clay content in soil. Since these two attributes contribute greatly for higher CEC.

4.2.2 Available nitrogen, phosphorus and potassium in soil

4.2.2.1 Available N in soil

Under custard apple based agri–horticulture system available nitrogen, phosphorus and potassium in soil varied significantly among different treatments and the values are presented in Table 4.4.

Irrespective of the treatments, the soil available N was lower during 2017 and 2018. Available N was found significantly higher in treatment CA + Cowpea (T_6)

(117.19 and 117.97 mg kg^{-1}) followed by CA + Field bean (T_3) (115.60 and 117.60 mg kg^{-1}), Cowpea alone (T_{13}) (108.95 and 109.53 mg kg^{-1}) and Field bean alone (T_{10}) (109.97 and 109.25 mg kg^{-1}) during 2017 and 2018, respectively. Fodder maize alone (T_9) (74.69 and 75.56 mg kg^{-1}) recorded significantly lower available N in the soil followed by T_2 (CA + Fodder maize) (76.86 and 80.87 mg kg^{-1}) during 2017 and 2018, respectively.

Pooled data of 2017 and 2018 revealed that, CA + Cowpea (T_6) (117.58 mg kg^{-1}) treatment maintained significantly higher available N in soil. However, this was on par with T_3 (CA + Field bean) (116.60 mg kg^{-1}) and T_{13} (Cowpea alone) (109.24 mg kg^{-1}). Higher available nitrogen under CA + Cowpea and CA + Field bean systems might be attributed to addition of nitrogen to soil through symbiotic nitrogen fixation and addition of organic matter in the form of leaf litter by the legumes as well as from custard apple. Swain *et al.,* (2012a) reported that cowpea and french bean intercropping in mango–based cropping system has helped in increasing the available N content of soil and this might be due to greater recycling of bio litters in the interspace with greater percentage of N. Similar results of increase in available N content of soil under intercropping in mango orchard have been showed by Swain and Patro (2007) and Ramulu (2014). Fodder maize alone (T_9) recorded significantly lower available N (75.12 mg kg^{-1}) which could be due to higher biomass production and higher nutrient uptake. The lower content of soil available nitrogen in the fodder maize treatments reflected the low content of organic matter. Organic matter has a direct influence on available N, this could be also attributed to the possibility of leaching of nitrogen in its soluble form as leaching is found to be accelerated by clearing of vegetation and higher percentage of sand content (Eludoyin and Wokocha, 2011). Decrease in nitrogen content might be due to nutrient removal from the biomass.

Whereas, the treatments T_1 (CA + Finger millet) (96.86 mg kg^{-1}), T_4 (CA + Niger) (95.20 mg kg^{-1}), T_5 (CA + Chilli) (98.99 mg kg^{-1}), T_7 (CA + Foxtail millet) (94.41 mg kg^{-1}), T_8 (Finger millet alone) (92.62 mg kg^{-1}) and T_{14} (Foxtail millet alone) (89.50 mg kg^{-1}) were found on par with each other.

4.2.2.2 Available P_2O_5 in soil

The available P_2O_5 content of soil differed significantly among treatments under custard apple based agri–horticulture system and the data are presented in Table 4.4.

During 2017 and 2018, significantly higher available P_2O_5 was found in treatment CA + Cowpea (T_6) (36.12 and 35.82 mg kg^{-1}, respectively). This was on par with CA + Field bean (T_3) (35.13 and 36.35 mg kg^{-1}), Cowpea alone (T_{13}) (33.14 and 34.32 mg kg^{-1}) and Field bean alone (T_{10}) (32.77 and 33.21 mg kg^{-1}) during 2017 and 2018, respectively. Significantly lower available P_2O_5 in soil was recorded in Fodder maize alone (T_9) (22.69 and 21.75 mg kg^{-1}) followed by T_2 (CA + Fodder maize) (23.71 and 22.25 mg kg^{-1}) during 2017 and 2018, respectively.

Pooled analysis of 2017 and 2018 data showed that, CA + Cowpea (T_6) (35.97 mg kg^{-1}) treatment maintained significantly higher available P_2O_5 in soil, which was on par with T_3 (CA + Field bean) (35.74 mg kg^{-1}), T_{13} (Cowpea alone) (33.73 mg kg^{-1}) and T_{10} (Field bean alone) (32.99 mg kg^{-1}). Increased available P_2O_5 in treatments with legume crops might be due to addition of higher crop residues to soil both from legumes and custard apple and subsequent decomposition and mineralization thus, releasing the P. The organic acids released during decomposition of leaf litter reduce the metal ions through chelation in soil and compete for exchange sites in soil, thus, releasing P from exchangeable sites in soil resulting in P availability. Root exudation of legumes and exchange or release of organic acids on the epidermal cell of root surfaces may enhance P availability (Meena *et al.,* 2017). CA + Fodder maize (T_2) (21.98 mg kg^{-1}) recorded significantly lower available P_2O_5 followed by Fodder maize alone (T_9) (22.22 mg kg^{-1}). This may be due to lower organic matter in soil as well as less addition of crop residues. It may also be due to fixation of native phosphorus by Fe and Al in soil. However, the treatments T_4 (CA + Niger) (29.14 mg kg^{-1}), T_5 (CA + Chilli) (31.81 mg kg^{-1}), T_7 (CA + Foxtail millet) (31.95 mg kg^{-1}), T_8 (Finger millet alone) (29.50 mg kg^{-1}) and T_{14} (28.74 mg kg^{-1}) were found on par with each other. It was also observed that the available P_2O_5 was higher under intercropping systems than sole crops of respective crops but the difference was non–significant. The increased available P in soil by intercropping under custard apple might be due to increased organic matter which intern improved the total

microflora population, particularly P solubilizes in the rhizosphere of plant (Swain *et al.,* 2012a). Similar findings on beneficial effects of intercropping in increasing P availability in the soil have been reported by Swain and Patro (2007).

4.2.2.3 Available K_2O in soil

The data on available K_2O content of soil as influenced by custard apple based agri–horticulture system are presented in Table 4.4. Custard apple based agri–horticulture system significantly influenced available K_2O content in soil during 2017 and 2018 as well as pooled data. CA + Cowpea (T_6) had significantly higher available K_2O (78.67 and 79.21 mg kg^{-1}) followed by T_3 (CA + Field bean) (76.51 and 78.46 mg kg^{-1}) and T_{13} (Cowpea alone) (75.10 and 73.31 mg kg^{-1}) during 2017 and 2018, respectively. Fodder maize alone (T_9) recorded significantly lower available K_2O (52.05 and 50.17 mg kg^{-1}) during 2017 and 2018, respectively. However, this was on par with T_2 (CA + Fodder maize) (53.88 and 54.71 mg kg^{-1} during 2017 and 2018, respectively).

Pooled analysis of data revealed that, available K_2O was found higher in treatment CA + Cowpea (T_6) (78.94 mg kg^{-1}) which was on par with T_3 (CA + Field bean) (77.49 mg kg^{-1}), T_{13} (Cowpea alone) (74.20 mg kg^{-1}) and T_{10} (Field alone) (73.97 mg kg^{-1}). Available K_2O was found non–significant among treatments T_4 (CA + Niger) (63.33 mg kg^{-1}), T_5 (CA + Chilli) (61.54 mg kg^{-1}), T_7 (CA + Foxtail millet) (64.92 mg kg^{-1}), T_8 (65.26 mg kg^{-1}) and T_{14} (62.85 mg kg^{-1}). Fodder maize alone (T_9) recorded significantly lower available K_2O (51.11 mg kg^{-1}) followed by T_2 (CA + Fodder maize) (54.29 mg kg^{-1}) which might be due to lower organic matter content in soil. It was also observed that intercropping systems contained higher available K_2O than sole crops of respective crops but the difference was non–significant. The increase in availability of K in soil under custard apple intercropped with legumes might be due to increased humus content of soil after decomposition of biomass of intercrops that builds up total population of beneficial microbes in the orchard soil coupled with solubilization of insoluble forms of K present in soil due to organic matter decomposition products. Similar results of improvement in potassium content of soil due to intercropping have been reported by Maheswarappa *et al.* (1998).

Table 4.4: Available N, P_2O_5 and K_2O content of soil as influenced by custard apple based agri–horticulture system before sowing of crops during 2017 and 2018

Treatments	Available N			Available P_2O_5			Available K_2O		
	(mg kg^{-1})								
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1: CA + Finger millet	95.84	97.87	96.86	31.84	33.63	32.73	71.33	72.50	71.92
T_2: CA + Fodder maize	76.86	80.87	78.86	23.71	22.25	21.98	53.88	54.71	54.29
T_3: CA + Field bean	115.60	117.60	116.60	35.13	36.35	35.74	76.51	78.46	77.49
T_4: CA + Niger	95.52	94.88	95.20	29.57	28.71	29.14	63.44	63.23	63.33
T_5: CA + Chilli	99.56	98.42	98.99	32.17	31.45	31.81	60.98	62.11	61.54
T_6: CA + Cowpea	117.19	117.97	117.58	36.12	35.82	35.97	78.67	79.21	78.94
T_7: CA + Foxtail millet	93.66	95.16	94.41	31.10	32.79	31.95	65.28	64.56	64.92
T_8: Finger millet alone	91.74	93.49	92.62	29.02	29.98	29.50	65.67	64.85	65.26
T_9: Fodder maize alone	74.69	75.56	75.12	22.69	21.75	22.22	52.05	50.17	51.11
T_{10}: Field bean alone	109.97	109.25	109.61	32.77	33.21	32.99	73.76	74.18	73.97
T_{11}: Niger alone	91.86	92.15	92.01	26.94	25.97	26.45	60.60	60.28	60.44
T_{12}: Chilli alone	96.03	93.91	94.97	31.59	29.81	30.70	61.06	59.25	60.15
T_{13}: Cowpea alone	108.95	109.53	109.24	33.14	34.32	33.73	75.10	73.31	74.20
T_{14}: Foxtail millet alone	89.08	89.91	89.50	29.03	28.46	28.74	62.59	63.11	62.85
T_{15}: Custard apple alone	90.02	89.34	89.68	24.22	24.64	24.43	60.59	58.11	59.35
S.Em ±	**4.67**	**5.40**	**3.47**	**2.22**	**1.39**	**1.34**	**3.71**	**2.98**	**2.06**
CD @ 5 %	**13.54**	**15.64**	**10.06**	**6.42**	**4.02**	**3.87**	**10.73**	**8.62**	**5.97**

Note: CA–Custard apple

4.2.3 Exchangeable calcium, magnesium and available sulphur in soil

There was a significant difference among the treatments with respect to exchangeable calcium, magnesium and available sulphur under custard apple based agri–horticulture system and the data is presented in Table 4.5. Significantly higher exchangeable Ca (3.36 and 3.43 cmol (p^+) kg^{-1}), Mg (2.14 and 2.15 cmol (p^+) kg^{-1}) and available S (19.77 and 19.44 mg kg^{-1}) was recorded under CA + Cowpea (T_6) during 2017 and 2018, respectively followed by T_3 (CA + Field bean). Significantly lower exchangeable Ca (2.71 and 2.67 cmol (p^+) kg^{-1}), Mg (1.43 and 1.49 cmol (p^+) kg^{-1}) and available S (12.30 and 13.31 mg kg^{-1}) was recorded under fodder maize alone during 2017 and 2018, respectively, which was on par with CA + Fodder maize.

Pooled data showed that significantly higher exchangeable Ca (3.40 cmol (p^+) kg^{-1}), Mg (2.15 cmol (p^+) kg^{-1}) and available S (19.60 mg kg^{-1}) was recorded under CA + Cowpea (T_6) followed by T_3 (CA + Field bean) (3.40, 2.14 cmol (p^+) kg^{-1} and 19.17 mg kg^{-1}, respectively). Higher exchangeable Ca, Mg and available S in intercropping systems is attributed to liberation of these nutrients from decomposed leaf litter as well as solubilization of insoluble forms present in soil due to decomposition of organic residues. Similar results were obtained by Lal *et al*. (2011) and Avinash Chandra Rathore *et al*. (2013). Arevalo *et al.* (2009) stated that increase in exchangeable Ca and Mg in soil was possibly brought about by weathering of minerals. The reason ascribed for such increase is accumulation of litter fall and tendency of neutral soil reactions under tree–based systems. Fodder maize alone (T_9) recorded significantly lower exchangeable Ca (2.69 cmol (p^+) kg^{-1}), Mg (1.46 cmol (p^+) kg^{-1}) and available S (12.80 mg kg^{-1}) which might be attributed to lower organic matter content in soil. It was also observed that intercropping systems contain higher exchangeable calcium, magnesium and available sulphur than sole crops of respective crops but the difference was non–significant.

Table 4.5: Exchangeable Ca, Mg and Available S content of soil as influenced by custard apple based agri–horticulture system before sowing of crops during 2017 and 2018

Treatments	Exchangeable Ca			Exchangeable Mg			Available S		
	(cmol (p+) kg^{-1})						(mg kg^{-1})		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1: CA + Finger millet	3.11	3.18	3.15	2.08	2.06	2.07	16.10	17.92	17.01
T_2: CA + Fodder maize	2.86	2.79	2.83	1.54	1.48	1.51	13.13	12.44	12.79
T_3: CA + Field bean	3.38	3.41	3.40	2.13	2.15	2.14	19.13	19.21	19.17
T_4: CA + Niger	2.94	2.95	2.95	1.91	1.94	1.93	16.57	17.67	17.12
T_5: CA + Chilli	2.89	2.82	2.86	1.82	1.79	1.81	17.40	16.23	16.82
T_6: CA + Cowpea	3.36	3.43	3.40	2.14	2.15	2.15	19.77	19.44	19.60
T_7: CA + Foxtail millet	3.12	3.09	3.11	1.92	1.93	1.92	16.80	18.15	17.48
T_8: Finger millet alone	2.95	2.91	2.93	1.98	2.02	2.00	16.53	17.08	16.81
T_9: Fodder maize alone	2.71	2.67	2.69	1.43	1.49	1.46	12.30	13.31	12.80
T_{10}: Field bean alone	3.34	3.32	3.33	2.08	2.11	2.10	19.00	21.24	20.12
T_{11}: Niger alone	2.87	2.90	2.89	1.93	1.90	1.92	16.17	16.47	16.32
T_{12}: Chilli alone	2.80	2.85	2.83	1.77	1.80	1.79	16.77	17.83	17.30
T_{13}: Cowpea alone	3.35	3.33	3.34	2.04	2.13	2.09	19.10	20.43	19.77
T_{14}: Foxtail millet alone	2.99	2.87	2.93	1.94	1.96	1.95	16.67	16.74	16.70
T_{15}: Custard apple alone	2.84	2.95	2.90	1.64	1.62	1.63	17.17	16.89	17.03
S.Em ±	**0.15**	**0.16**	**0.15**	**0.09**	**0.10**	**0.10**	**0.85**	**0.84**	**0.53**
CD @ 5 %	**0.42**	**0.46**	**0.42**	**0.26**	**0.30**	**0.28**	**2.48**	**2.43**	**1.54**

Note: CA–Custard apple

4.2.4 Micronutrient content in soil

Custard apple based agri–horticulture system significantly influenced the micronutrient content during 2017 and 2018 and the data are presented in Table 4.6. Significantly higher Fe (16.28 and 15.89 mg kg^{-1}), Mn (41.60 and 40.74 mg kg^{-1}), Zn (3.31 and 3.32 mg kg^{-1}) and Cu (1.43 and 1.42 mg kg^{-1}) was noticed in treatment CA + Cowpea (T_6) during 2017 and 2018, respectively which was followed by CA + Field bean (T_3), Cowpea alone (T_{13}) and Field bean alone (T_{10}). Significantly lower Fe (7.24 and 7.09 mg kg^{-1}), Mn (26.60 and 24.87 mg kg^{-1}), Zn (2.66 and 2.65 mg kg^{-1}) and Cu (0.69 and 0.68 mg kg^{-1}) was recorded in treatment Fodder maize alone (T_9) during 2017 and 2018, respectively.

Pooled data revealed that, significantly higher Fe, Mn, Zn and Cu were found in treatment CA + Cowpea (T_6) (16.09, 41.17, 3.31 and 1.43 mg kg^{-1}, respectively) and this was followed by T_3 (CA + Field bean) (15.51, 39.71, 3.30 and 1.28 mg kg^{-1}, respectively). Increased micronutrient content in these treatments might be due to presence of higher organic matter content, since organic matter is the major source of micronutrients in soil. This may also be due to addition of crop residues from legume crops and custard apple leaf litter. During decomposition of these crop residues, increased solubility of micronutrients by decreasing soil pH due to production of organic acids. Similar results were also reported by Hemalatha and Chellamuthu (2013) and Vinod Kumar and Chopra (2016). Fodder maize alone (T_9) recorded significantly lower Fe (7.17 mg kg^{-1}), Mn (25.74 mg kg^{-1}), Zn (2.65 mg kg^{-1}) and Cu (0.69 mg kg^{-1}) followed by T_2 (CA + Fodder maize). It was also observed that intercropping systems have relatively recorded higher micronutrients than sole crops of respective crops but the difference was non–significant. The increase in total micronutrient content in soil profile under different land -use systems could be attributed to weathering of rocks through growing tree roots and contribution by root biomass (Sharma *et al.,* 2009). Babu *et al.,* (2007) reported that soils with good organic matter content have high micronutrient availability due to chelating action of organic compounds released during decomposition and prevention of cations from fixation, precipitation, oxidation and leaching.

Table 4.6: Micronutrients content of soil as influenced by custard apple based agri–horticulture system before sowing of crops during 2017 and 2018

Treatments	Fe			Mn			Zn			Cu		
	(mg kg^{-1})											
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
T_1: CA + Finger millet	12.70	12.74	12.72	34.32	35.63	34.98	2.74	2.81	2.78	1.09	0.99	1.04
T_2: CA + Fodder maize	9.10	8.98	9.04	28.12	27.78	27.95	2.61	2.57	2.59	0.76	0.73	0.75
T_3: CA + Field bean	15.54	15.48	15.51	39.77	39.64	39.71	3.27	3.33	3.30	1.36	1.38	1.37
T_4: CA + Niger	14.53	14.63	14.58	38.22	36.87	37.55	3.03	3.06	3.05	1.25	1.30	1.28
T_5: CA + Chilli	11.44	12.08	11.76	33.64	33.27	33.46	2.75	2.69	2.72	1.02	1.04	1.03
T_6: CA + Cowpea	16.28	15.89	16.09	41.60	40.74	41.17	3.31	3.32	3.31	1.43	1.42	1.43
T_7: CA + Foxtail millet	13.54	13.57	13.56	34.50	34.29	34.39	3.14	3.12	3.13	1.24	1.29	1.27
T_8: Finger millet alone	12.17	12.13	12.15	33.24	33.51	33.38	2.71	2.76	2.74	0.95	1.02	0.99
T_9: Fodder maize alone	7.24	7.09	7.17	26.60	24.87	25.74	2.66	2.65	2.65	0.69	0.68	0.69
T_{10}: Field bean alone	15.14	14.98	15.06	38.83	37.73	38.28	3.24	3.28	3.26	1.26	1.32	1.29
T_{11}: Niger alone	13.74	14.02	13.88	37.53	36.29	36.91	2.98	3.04	3.01	1.18	1.21	1.20
T_{12}: Chilli alone	10.96	11.24	11.10	31.60	32.08	31.84	2.69	2.66	2.68	1.00	1.05	1.03
T_{13}: Cowpea alone	15.29	15.14	15.21	38.94	37.56	38.25	3.25	3.30	3.28	1.32	1.32	1.32
T_{14}: Foxtail millet alone	12.24	12.39	12.31	34.28	34.29	34.29	3.06	3.11	3.09	1.18	1.14	1.16
T_{15}: Custard apple alone	9.68	10.01	9.85	29.38	28.72	29.05	2.78	2.72	2.75	0.92	0.91	0.92
S.Em ±	**0.60**	**0.66**	**0.62**	**1.82**	**1.63**	**1.71**	**0.14**	**0.14**	**0.14**	**0.06**	**0.06**	**0.06**
CD @ 5 %	**1.73**	**1.91**	**1.81**	**5.27**	**4.72**	**4.95**	**0.41**	**0.41**	**0.41**	**0.18**	**0.17**	**0.17**

Note: CA–Custard apple

4.3 Effect of custard apple based agri–horticulture system on soil biological properties before sowing of crops during 2017 and 2018

4.3.1 Dehydrogenase activity in soil

Dehydrogenase, is considered as an intracellular enzyme, may be extruded in soil due to cell lysis and associated with organic matter or soil colloidal surfaces (Nannipieri *et al.,* 2002). Custard apple based agri–horticulture system significantly influenced the dehydrogenase activity in soil during 2017 and 2018 and the data are presented in Table 4.7. During 2017 and 2018 significantly higher dehydrogenase activity was noticed in treatment CA + Cowpea (T_6) (57.64 and 60.52 µg TPF g^{-1} of soil day^{-1}, respectively) followed by T_3 (CA + Field bean) (54.32 and 58.69 µg TPF g^{-1} of soil day^{-1}, respectively) and T_{13} (Cowpea alone) (51.43 and 53.89 µg TPF g^{-1} of soil day^{-1}, respectively). Among the different treatments, significantly lower dehydrogenase activity (35.66 and 37.09 µg TPF g^{-1} of soil day^{-1}, respectively) was recorded in Fodder maize alone (T_9) during 2017 and 2018 which was on par with T_2 (CA + Fodder maize) (37.67 and 40.66 µg TPF g^{-1} of soil day^{-1}, respectively).

Pooled analysis of 2017 and 2018 showed that, among the treatments significantly higher dehydrogenase activity (59.08 µg TPF g^{-1} of soil day^{-1}) was recorded in treatment CA + Cowpea (T_6). However, this was on par with treatments T_3 (CA + Field bean) (56.51 µg TPF g^{-1} of soil day^{-1}), T_{13} (Cowpea alone) (52.66 µg TPF g^{-1} of soil day^{-1}) and T_{10} (Field bean alone) (51.73 µg TPF g^{-1} of soil day^{-1}). Significantly higher dehydrogenase activity in treatments with legume crops might be due to increased organic matter content in these treatments since activity of dehydrogenase had a direct relationship with the organic matter content of the soil (Wlodarczyk *et al.,* 2002). Thus, the addition of organic matter is important in maintaining higher dehydrogenase activities. This maximum activity might be linked to more substrate availability in these treatments. This reflects greater biological activity in these plots and the stabilization of extracellular enzymes through complexation with humic substances. Dehydrogenase activity was found to be non–significant among the treatments T_1 (CA + Finger millet) (47.57 µg TPF g^{-1} of soil day^{-1}), T_4 (CA + Niger) (46.36 µg TPF g^{-1} of soil day^{-1}), T_5 (CA + Chilli) (45.99 µg TPF g^{-1} of soil day^{-1}), T_7 (CA + Foxtail millet) (43.95 µg TPF g^{-1} of

soil day^{-1}), T_8 (Finger millet alone) (44.18 µg TPF g^{-1} of soil day^{-1}), T_{12} (Chilli alone) (44.23 µg TPF g^{-1} of soil day^{-1}) and T_{14} (Foxtail millet alone) (43.10 µg TPF g^{-1} of soil day^{-1}). Significantly lower dehydrogenase activity (36.38 µg TPF g^{-1} of soil day^{-1}) was recorded in Fodder maize alone (T_9) but it was on par with T_{15} (Custard apple alone) (38.24 µg TPF g^{-1} of soil day^{-1}) and T_2 (CA + Fodder field) (39.17 µg TPF g^{-1} of soil day^{-1}). The decrease in dehydrogenase activity in these treatments could be attributed to the lower organic matter content in soil since, activity of enzymes depends on this. It was also observed that with respect to specific crops dehydrogenase activity was higher under intercrops than sole crops, this support the hypothesis that permanent vegetative cover provides favourable conditions for a balanced soil functional diversity reflected by higher dehydrogenase activities compared with soils under sole crops. Increased enzyme activities in these treatments are attributed to increased organic matter and litter quality and quantity as well as improved soil physical characters (Ranjith Udawatta *et al.,* 2009). The importance of organic carbon in soil was evident from the fact that the enzyme activity measured in the present study showed significant positive correlation with organic carbon.

4.3.2 Urease activity in soil

Urease, an important enzyme, responsible for the hydrolysis of urea fertilizer applied to the soil into NH_3 and CO_2 with the concomitant rise in soil pH. Soil urease is produced by soil microbes which play a vital role in nitrogen cycle by hydrolysis of urea into ammonia, carbon dioxide and water which are beneficial for plants absorption (Zhang *et al.,* 2004). To some extent urease is an indicator of plant N availability in different cropping systems and environments (He *et al.,* 2010). Urease activity varied significantly under custard apple based agri–horticulture system during 2017 and 2018 and the data are presented in Table 4.7. Among the treatments, significantly higher (7.98 and 8.38 µg NH_4–N g^{-1} of soil hr^{-1}) urease activity was found in treatment CA + Cowpea (T_6) during 2017 and 2018, respectively. However, this was found on par with T_3 (CA + Field bean) (7.63 and 8.40 µg NH_4–N g^{-1} of soil hr^{-1}). Fodder maize alone (T_9) recorded significantly lower (4.27 and 4.44 µg NH_4–N g^{-1} of soil hr^{-1}) urease activity during 2017

and 2018, respectively and this was on par with T_{15} (Custard apple alone) (4.30 and 4.47 µg NH_4–N g^{-1} of soil hr^{-1}).

Results of the pooled analysis revealed that, CA + Cowpea (T_6) recorded significantly higher (8.18 µg NH_4–N g^{-1} of soil hr^{-1}) urease activity which was on par with T_3 (CA + Field bean) (8.02 µg NH_4–N g^{-1} of soil hr^{-1}). Significantly higher urease activity in treatments with legume crops might be due to their higher N content and faster decomposition and release of NH_4 -N. Enzyme activities of soils are usually correlated with their organic carbon and available N contents (Taylor *et al.,* 2002). Higher levels of organic carbon in soil stimulate microbial activity and therefore enzyme activities. It was found non–significant among T_4 (CA + Niger) (6.26 µg NH_4–N g^{-1} of soil hr^{-1}), T_5 (CA + Chilli) (5.55 µg NH_4–N g^{-1} of soil hr^{-1}), T_8 (Finger millet alone) (5.55 µg NH_4–N g^{-1} of soil hr^{-1}), T_{12} (Chilli alone) (5.57 µg NH_4–N g^{-1} of soil hr^{-1}) and T_{14} (Foxtail millet alone) (5.72 µg NH_4–N g^{-1} of soil hr^{-1}). CA + Fodder maize (T_2) recorded significantly lower (4.30 µg NH_4–N g^{-1} of soil hr^{-1}) urease activity followed by Fodder maize alone (T_9) (4.36 µg NH_4–N g^{-1} of soil hr^{-1}) and T_{15} (Custard apple alone) (4.38 µg NH_4–N g^{-1} of soil hr^{-1}). The variation in urease activity among different treatments might be due to variation in soil organic matter/carbon content and microbial biomass nitrogen since; urease activity is directly related to amount of organic matter present in soil (Renato Roscoe *et al.,* 2000).

4.3.3 Acid and alkaline phosphatase activity in soil

Phosphatase is one of very important enzymes and plays a vital role to transfer organic P into inorganic phosphate which is directly available to plants and soil organisms. Acid and alkaline phosphatase activity varied significantly under custard apple based agri–horticulture system during 2017 and 2018 and the data are presented in Table 4.7. In the present study, acid phosphatase activity was higher than alkaline phosphatase activity, which might be due to the acidity of the soil since phosphatase activity is strongly influenced by soil pH. Acid phosphatase prevails in acid soils and alkaline phosphatase prevails in alkaline soils (Balota *et al.,* 2004).

Significantly higher acid (27.81 and 30.20 µg PNP g^{-1} of soil hr^{-1}) and alkaline (16.68 and 18.51 µg PNP g^{-1} of soil hr^{-1}) phosphatase activities were noticed in treatment CA + Cowpea (T_6) during 2017 and 2018, respectively. Significantly lower acid (18.90 and 19.66 µg PNP g^{-1} of soil hr^{-1}) and alkaline (10.08 and 10.48 µg PNP g^{-1} of soil hr^{-1}) phosphatase activities were noticed in Fodder maize alone (T_9) during 2017 and 2018, respectively.

Pooled analysis of 2017 and 2018 experimental data showed that, CA + Cowpea (T_6) recorded significantly higher acid (29.01 µg PNP g^{-1} of soil hr^{-1}) and alkaline (17.60 µg PNP g^{-1} of soil hr^{-1}) phosphatase activities followed by T_3 (CA + Field bean) (28.10 and 16.68 µg PNP g^{-1} of soil hr^{-1}, respectively). Significantly higher acid and alkaline phosphatase activity in treatments with legume crops might be due to greater plant - derived phosphatase with growth of custard apple with additional production of acid phosphatase with legumes by free root nodule bacteria, during the initiation of symbiosis. Increased phosphatase activity might also be due increased organic matter content of soil which might have improved microbial activity. These results are in conformity with (George *et al.,* 2002). The acid and alkaline phosphatase activities were found non–significant among T_1 (CA + Finger millet) (24.54 and 13.20 µg PNP g^{-1} of soil hr^{-1}, respectively), T_5 (CA + Chilli) (23.20 and 12.79 µg PNP g^{-1} of soil hr^{-1}, respectively), T_7 (CA + Foxtail millet) (23.90 and 12.67 µg PNP g^{-1} of soil hr^{-1}, respectively), T_8 (Finger millet alone) (22.66 and 12.84 µg PNP g^{-1} of soil hr^{-1}, respectively), T_{11} (Niger alone) (21.88 and 13.43 µg PNP g^{-1} of soil hr^{-1}, respectively) and T_{14} (Foxtail millet alone) (22.59 and 12.82 µg PNP g^{-1} of soil hr^{-1}, respectively). Significantly lower acid (19.28 µg PNP g^{-1} of soil hr^{-1}) and alkaline (10.28 µg PNP g^{-1} of soil hr^{-1}) phosphatase activities were recorded in treatment Fodder maize alone (T_9). Significantly lower acid and alkaline phosphatase activities under fodder maize might be due to lower organic carbon content in soil which acts as energy for enzyme activity. It was also observed that with respect to individual crop, acid and alkaline phosphatase activity was higher under intercrops than sole crops. Higher activity of phosphatase enzyme under intercropping systems might be due to higher organic matter addition along with inorganic fertilizer which intern increased the organic carbon and nitrogen (Kadlag *et al.,* 2008).

Table 4.7: Dehydrogenase, urease and phosphatase activity in soil as influenced by custard apple based agri–horticulture system before sowing of crops during 2017 and 2018

Treatments	Dehydrogenase (µg TPF g^{-1} of soil day^{-1})			Urease (µg NH_4-N g^{-1} dry soil hr^{-1})			Acid Phosphatase (µg PNP g^{-1} of dry soil hr^{-1})			Alkaline Phosphatase (µg PNP g^{-1} of dry soil hr^{-1})		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1: CA + Finger millet	46.18	48.95	47.57	6.22	7.13	6.68	23.34	25.74	24.54	12.81	13.58	13.20
T_2: CA + Fodder maize	37.67	40.66	39.17	4.48	4.12	4.30	21.34	22.02	21.68	10.63	10.78	10.71
T_3: CA + Field bean	54.32	58.69	56.51	7.63	8.40	8.02	26.49	29.70	28.10	15.41	17.95	16.68
T_4: CA + Niger	45.77	46.94	46.36	5.88	6.64	6.26	23.48	23.54	23.51	13.12	13.60	13.36
T_5: CA + Chilli	44.89	47.09	45.99	5.67	5.44	5.55	22.66	23.75	23.20	13.05	12.53	12.79
T_6: CA + Cowpea	57.64	60.52	59.08	7.98	8.38	8.18	27.81	30.20	29.01	16.68	18.51	17.60
T_7: CA + Foxtail millet	44.39	43.50	43.95	6.04	6.92	6.48	23.13	24.67	23.90	12.49	12.84	12.67
T_8: Finger millet alone	42.89	45.46	44.18	5.78	5.32	5.55	22.04	23.28	22.66	12.61	13.06	12.84
T_9: Fodder maize alone	35.66	37.09	36.38	4.27	4.44	4.36	18.90	19.66	19.28	10.08	10.48	10.28
T_{10}: Field bean alone	50.75	52.71	51.73	6.45	6.56	6.51	24.81	26.32	25.57	14.62	15.74	15.18
T_{11}: Niger alone	43.65	46.71	45.18	5.29	5.66	5.48	21.63	22.14	21.88	12.97	13.88	13.43
T_{12}: Chilli alone	44.22	44.24	44.23	5.31	5.83	5.57	21.06	22.16	21.61	13.23	12.84	13.04
T_{13}: Cowpea alone	51.43	53.89	52.66	6.77	6.57	6.67	26.31	27.52	26.92	15.54	15.97	15.76
T_{14}: Foxtail millet alone	42.81	43.10	42.96	5.63	5.80	5.72	22.03	23.15	22.59	13.08	12.56	12.82
T_{15}: Custard apple alone	37.49	38.99	38.24	4.30	4.47	4.38	19.26	20.03	19.65	12.03	12.51	12.27
S.Em ±	**2.17**	**2.43**	**2.29**	**0.31**	**0.29**	**0.30**	**1.43**	**1.16**	**1.25**	**0.69**	**0.66**	**0.67**
CD @ 5 %	**6.28**	**7.05**	**6.63**	**0.91**	**0.85**	**0.87**	**4.13**	**3.36**	**3.61**	**1.99**	**1.92**	**1.95**

Note: CA–Custard apple

Further, the organic acids produced during decomposition of organic matter might have resulted in enhanced enzyme activity. Similar results were also reported by Srilatha *et al.* (2013).

4.3.4 Microbial biomass carbon content

Soil microbial biomass, a living part of soil organic matter, is an agent of transformation for added and native organic matter and acts as a labile reservoir for plant -available nitrogen, phosphorus and sulphur (Jenkinson and Ladd, 1981). Soil microbial biomass C is an important index to evaluate soil microbial numbers, activity, and soil fertility (Hu *et al.,* 2006). Microbial biomass C significantly varied among the treatments under custard apple based agri–horticulture system during 2017 and 2018 and the data are presented in Table 4.8. During 2017 and 2018, significantly higher (322.42 and 330.54 mg kg^{-1}, respectively) microbial biomass C was noticed in treatment CA + Cowpea (T_6) and this was followed by T_3 (CA + Field bean) (314.91 and 325.46 mg kg^{-1}, respectively). Significantly lower (228.43 and 227.57 mg kg^{-1}, respectively) microbial biomass C was recorded under Fodder maize alone (T_9) during 2017 and 2018. However, this was on par with T_{15} (Custard apple alone) (229.63 and 230.82 mg kg^{-1}, respectively) and T_2 (CA + Fodder maize) (233.64 and 234.95 mg kg^{-1}, respectively) during 2017 and 2018.

Pooled analysis showed that CA + Cowpea (T_6) maintained significantly higher (326.48 mg kg^{-1}) microbial biomass C. However, this was on par with treatments T_3 (CA + Field bean) (320.19 mg kg^{-1}), T_{13} (Cowpea alone) (311.99 mg kg^{-1}) and T_{10} (Field bean alone) (307.53 mg kg^{-1}). Significantly higher microbial biomass C in treatments with legume crops might be due to increased organic matter content in soil due to addition of large crop residues from both main crop as well as intercrop along with FYM. Legumes are one of the important components to increase soil microbial biomass (SMB) in soils (Siddique *et al.,* 2008; Deakin and Broughton, 2009). The SMB is increased by legume -based rotations, with significant improvement in soil microbial community structure and soil health (Chintala *et al.,* 2013).

The microbial biomass C was found non–significant among the treatments T_1 (CA + Finger millet) (251.19 mg kg^{-1}), T_4 (CA + Niger) (246.31 mg kg^{-1}), T_7 (CA + Foxtail millet) (235.48 mg kg^{-1}), T_8 (Finger millet alone) (247.27 mg kg^{-1}), T_{11} (Niger alone) (238.02 mg kg^{-1}) and T_{14} (Foxtail millet alone) (231.55 mg kg^{-1}). Significantly lower (228.00 mg kg^{-1}) microbial biomass C was recorded in treatment Fodder maize alone (T_9) which was followed by T_{15} (Custard apple alone) (230.23 mg kg^{-1}) and T_2 (CA + Fodder maize) (234.30 mg kg^{-1}). Significantly lower microbial biomass C in fodder maize might be due to decrease in organic matter content of soil due to less addition of crop residues to soil and decreased microbial activity. It was also noticed that with respect to specific crops microbial biomass C was higher under intercrops than sole crops. The greater microbial biomass in the intercropping treatments reflects the addition of more organic matter to the soil under tree -crop combinations. These results suggested that adoption of agri–horticulture system could lead to increased soil fertility by improving soil organic matter, available nutrients and microbial biomass in soil. Chander *et al.* (1998) reported that tree–crop combination increased long–term sustainability of soil fertility by improving levels of soil organic matter, available nutrients and soil microbial activity. Both the amounts of microbial biomass C as well as dehydrogenase and alkaline phosphatase activities were greater in soils under *D. sissoo*. In soil where only crops were grown, the microbial biomass and enzyme activities were lowest.

4.3.5 Microbial biomass nitrogen content

Under custard apple based agri–horticulture system, microbial biomass N significantly varied among the treatments during 2017 and 2018 and the data are presented in Table 4.8. Significantly higher (37.62 and 38.56 mg kg^{-1}) microbial biomass N was recorded in treatment CA + Cowpea (T_6) which was followed by T_3 (CA + Field bean) (36.74 and 37.97 mg kg^{-1}) during 2017 and 2018, respectively. Significantly lower (26.65 and 26.55 mg kg^{-1}, respectively) microbial biomass N was noticed under Fodder maize alone (T_9) during 2017 and 2018. However, this was on par with T_2 (CA + Fodder maize) (27.26 and 27.41 mg kg^{-1}, respectively) during 2017 and 2018.

Pooled analysis of 2017 and 2018 experimental data revealed that CA + Cowpea (T_6) maintained significantly higher (38.09 mg kg^{-1}) microbial biomass N. However, this was on par with treatments T_3 (CA + Field bean) (37.36 mg kg^{-1}), T_{13} (Cowpea alone) (36.40 mg kg^{-1}) and T_{10} (Field bean alone) (35.88 mg kg^{-1}). Significantly higher microbial biomass N in treatments with legume crops might be due to increased organic matter content in soil due to addition of higher crop residues along with FYM. It could be attributed to addition of varying quantity of organic matter inputs over the years through litter fall from both crops (Yadav *et al.,* 2008). Moreover, the higher amounts of soil microbial biomass N under treatments with legume cropping systems could be due to fixation of larger atmospheric nitrogen by leguminous crops like cowpea and field bean. Similar findings were also reported by Ullah *et al.* (2012). The microbial biomass N was found on par among the treatments T_4 (CA + Niger) (28.74 mg kg^{-1}), T_7 (CA + Foxtail millet) (27.47 mg kg^{-1}), T_8 (Finger millet alone) (28.85 mg kg^{-1}), T_{11} (Niger alone) (27.77 mg kg^{-1}) and T_{14} (Foxtail millet alone) (27.01 mg kg^{-1}). Significantly lower (26.60 mg kg^{-1}) microbial biomass N was recorded in treatment Fodder maize alone (T_9) which was followed by T_{15} (Custard apple alone) (26.80 mg kg^{-1}) and T_2 (CA + Fodder maize) (27.34 mg kg^{-1}). Significantly lower microbial biomass N in fodder maize might be due to low soil organic carbon content, as both carbon and nitrogen are complementary to each other. These results corroborate the findings of Verma and Mathur (2009); Kumari *et al.* (2011). These fluctuations could be due to variations in soil moisture and temperature, crop species and available substrate. Small shifts in the structure of the microbial community can result in large chances in biomass nitrogen (Ramulu, 2014).

4.3.6 Microbial biomass phosphorus content

Custard apple based agri–horticulture system significantly influenced the microbial biomass P content in soil and it varied significantly among the treatments during 2017 and 2018 and the data are presented in Table 4.8. Microbial biomass P was recorded significantly higher (3.63 and 3.71 mg kg^{-1}) in treatment CA + Cowpea (T_6) which was followed by T_3 (CA + Field bean) (3.47 and 3.62 mg kg^{-1}) during 2017 and 2018, respectively. Significantly lower (1.56 and 1.62 mg kg^{-1}, respectively) microbial biomass P was noticed under Fodder maize alone (T_9) during 2017 and 2018.

Table 4.8: Microbial biomass carbon (C), nitrogen (N) and phosphorus (P) in soil as influenced by custard apple based agri–horticulture system before sowing of crops during 2017 and 2018

Treatments	Microbial Biomass C			Microbial Biomass N			Microbial Biomass P		
	(mg kg^{-1})								
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1: CA + Finger millet	248.73	253.65	251.19	29.02	29.59	29.31	2.98	3.16	3.07
T_2: CA + Fodder maize	233.64	234.95	234.30	27.26	27.41	27.34	2.05	2.29	2.17
T_3: CA + Field bean	314.91	325.46	320.19	36.74	37.97	37.36	3.47	3.62	3.55
T_4: CA + Niger	241.13	251.48	246.31	28.13	29.34	28.74	2.86	2.95	2.91
T_5: CA + Chilli	281.63	280.36	281.00	32.86	32.71	32.78	2.74	2.83	2.79
T_6: CA + Cowpea	322.42	330.54	326.48	37.62	38.56	38.09	3.63	3.71	3.67
T_7: CA + Foxtail millet	232.81	238.15	235.48	27.16	27.79	27.47	2.56	2.61	2.59
T_8: Finger millet alone	247.15	247.38	247.27	28.84	28.86	28.85	2.89	2.86	2.88
T_9: Fodder maize alone	228.43	227.57	228.00	26.65	26.55	26.60	1.56	1.62	1.59
T_{10}: Field bean alone	304.67	310.39	307.53	35.54	36.21	35.88	3.12	3.23	3.18
T_{11}: Niger alone	239.63	236.40	238.02	27.96	27.58	27.77	2.64	2.82	2.73
T_{12}: Chilli alone	276.49	281.61	279.05	32.25	32.85	32.55	2.71	2.77	2.74
T_{13}: Cowpea alone	311.66	312.31	311.99	36.36	36.44	36.40	3.39	3.45	3.42
T_{14}: Foxtail millet alone	231.18	231.93	231.55	26.97	27.06	27.01	2.45	2.53	2.49
T_{15}: Custard apple alone	229.63	230.82	230.23	26.79	26.93	26.86	1.72	1.79	1.76
S.Em ±	**12.71**	**14.00**	**13.18**	**1.76**	**1.50**	**1.61**	**0.13**	**0.15**	**0.14**
CD @ 5 %	**36.81**	**40.56**	**38.17**	**5.09**	**4.34**	**4.65**	**0.37**	**0.42**	**0.39**

Note: CA–Custard apple

However, this was on par with T_{15} (Custard apple alone) (1.72 and 1.79 mg kg^{-1}, respectively) during 2017 and 2018 followed by T_2 (CA + Fodder maize) (2.05 and 2.29 mg kg^{-1}, respectively).

Pooled data revealed that CA + Cowpea (T_6) maintained significantly higher (3.67 mg kg^{-1}) microbial biomass P. However, this was on par with treatments T_3 (CA + Field bean) (3.55 mg kg^{-1}) and T_{13} (Cowpea alone) (3.42 mg kg^{-1}). It could be attributed mainly due to addition of varying quantity of organic matter inputs through litter fall from both crops. These results are in conformity with Yadav *et al.* (2008). More microbial biomass P under legume treatments might also be due to more affiliation and interaction of P–phosphate solubilizing microorganisms with cowpea and field bean crops, which resulted in more soil microbial biomass P contents. Similar results were reported by Ullah *et al.* (2013) in case of mungbean. The microbial biomass P was found non–significant among the treatments T_1 (CA + Finger millet) (3.07 mg kg^{-1}), T_4 (CA + Niger) (2.91 mg kg^{-1}), T_5 (CA + Chilli) (2.79 mg kg^{-1}) and T_8 (Finger millet alone) (2.88 mg kg^{-1}). Significantly lower (1.59 mg kg^{-1}) microbial biomass P was recorded in treatment Fodder maize alone (T_9) followed by T_{15} (Custard apple alone) (1.76 mg kg^{-1}) and T_2 (CA + Fodder maize) (2.17 mg kg^{-1}). Significantly lower microbial biomass P in fodder maize might be due to lower organic carbon and microbial biomass carbon content compared to other treatments. It was also observed that with respect to specific crops microbial biomass P was higher under intercrops than sole crops may be due to relatively higher organic carbon content and higher substrate availability for microbes.

4.4 Effect of custard apple based agri–horticulture system on soil carbon dynamics

4.4.1 Effect of custard apple based agri–horticulture system on soil organic carbon content at different depths

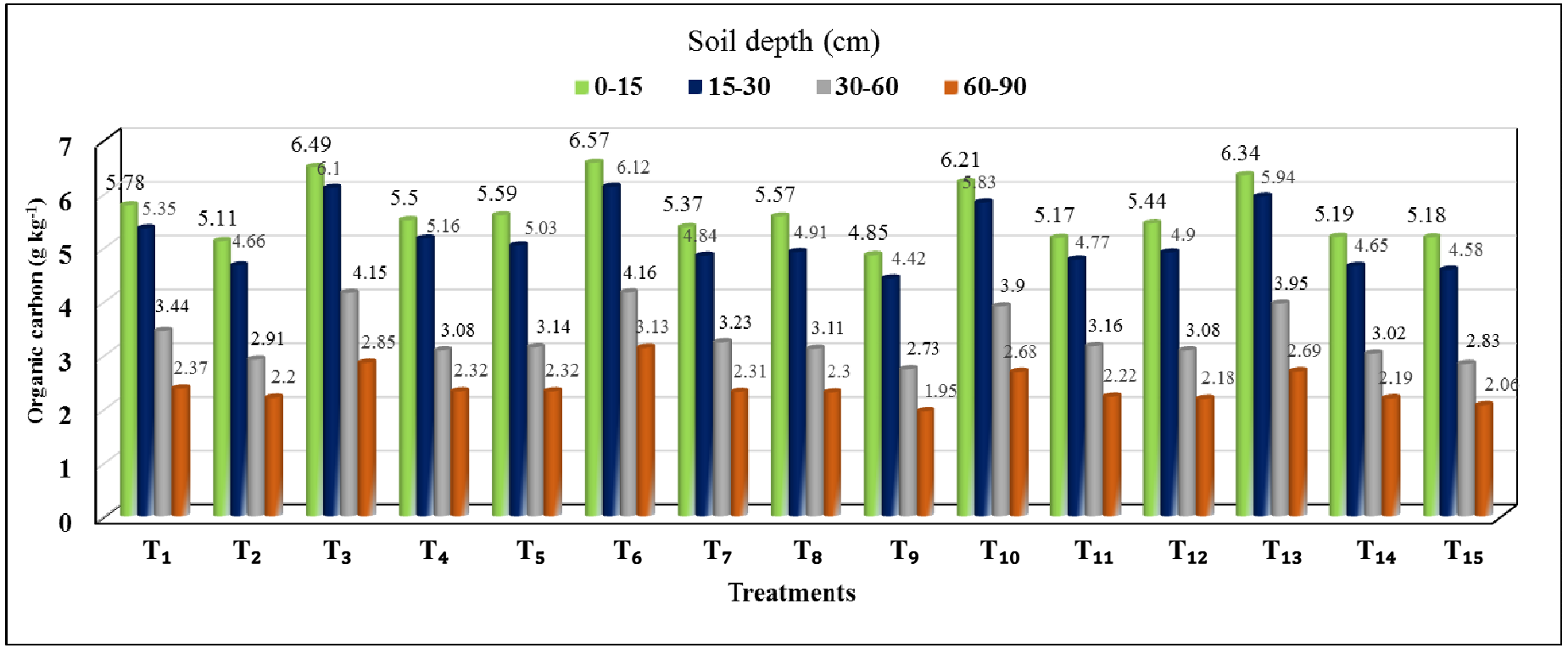
The custard apple based agri–horticulture system significantly influenced the soil organic carbon content at different depths and the data are presented in Table 4.9 and Figure 4.1.

During 2017 and 2018 soil organic carbon (SOC) content showed a significant difference among the different treatments at all depths with higher organic carbon content

Table 4.9: Soil organic carbon content (g kg^{-1}) at different depths as influenced by custard apple based agri–horticulture system after harvest of crops during 2017 and 2018

Treatments	Soil depth (cm)											
	0-15			15-30			30-60			60-90		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1: CA + Finger millet	5.77	5.79	5.78	5.35	5.34	5.35	3.42	3.45	3.44	2.35	2.38	2.37
T_2: CA + Fodder maize	5.10	5.11	5.11	4.65	4.66	4.66	2.90	2.91	2.91	2.19	2.22	2.20
T_3: CA + Field bean	6.48	6.49	6.49	6.09	6.10	6.10	4.13	4.16	4.15	2.84	2.86	2.85
T_4: CA + Niger	5.49	5.51	5.50	5.16	5.15	5.16	3.07	3.08	3.08	2.31	2.33	2.32
T_5: CA + Chilli	5.58	5.60	5.59	5.02	5.04	5.03	3.12	3.15	3.14	2.32	2.31	2.32
T_6: CA + Cowpea	6.56	6.57	6.57	6.11	6.13	6.12	4.15	4.16	4.16	3.12	3.13	3.13
T_7: CA + Foxtail millet	5.36	5.38	5.37	4.83	4.85	4.84	3.21	3.24	3.23	2.33	2.30	2.31
T_8: Finger millet alone	5.57	5.56	5.57	4.92	4.89	4.91	3.10	3.12	3.11	2.29	2.30	2.30
T_9: Fodder maize alone	4.85	4.85	4.85	4.41	4.43	4.42	2.73	2.73	2.73	1.94	1.95	1.95
T_{10}: Field bean alone	6.20	6.22	6.21	5.84	5.82	5.83	3.89	3.92	3.90	2.68	2.68	2.68
T_{11}: Niger alone	5.16	5.18	5.17	4.76	4.78	4.77	3.16	3.16	3.16	2.21	2.23	2.22
T_{12}: Chilli alone	5.42	5.45	5.44	4.91	4.88	4.90	3.07	3.10	3.08	2.19	2.17	2.18
T_{13}: Cowpea alone	6.32	6.35	6.34	5.95	5.93	5.94	3.94	3.96	3.95	2.70	2.68	2.69
T_{14}: Foxtail millet alone	5.19	5.18	5.19	4.66	4.65	4.65	3.02	3.02	3.02	2.18	2.19	2.19
T_{15}: Custard apple alone	5.16	5.19	5.18	4.59	4.57	4.58	2.82	2.83	2.83	2.06	2.07	2.06
S.Em ±	**0.27**	**0.27**	**0.27**	**0.26**	**0.25**	**0.25**	**0.24**	**0.17**	**0.20**	**0.12**	**0.11**	**0.12**
CD @ 5 %	**0.78**	**0.78**	**0.78**	**0.76**	**0.72**	**0.74**	**0.69**	**0.51**	**0.57**	**0.35**	**0.33**	**0.34**

Note: CA–Custard apple



T_1: CA + Finger millet
T_2: CA + Fodder maize
T_3: CA + Field bean
T_4: CA + Niger
T_5: CA + Chilli
T_6: CA + Cowpea
T_7: CA + Foxtail millet
T_8: Finger millet alone
T_9: Fodder maize alone
T_{10}: Field bean alone
T_{11}: Niger alone
T_{12}: Chilli alone
T_{13}: Cowpea alone
T_{14}: Foxtail millet alone
T_{15}: Custard apple alone

Fig. 4.1: Organic carbon content (g kg^{-1}) in soil at different depths as influenced by custard apple based agri-horticulture system after harvest of crops

under treatments with legume crops. At 0–15 cm soil depth, significantly higher soil organic carbon was noticed during 2017 and 2018 in treatment CA + Cowpea (6.56 and 6.57 g kg^{-1}, respectively) (T_6) followed by CA + Field bean (6.48 and 6.49 g kg^{-1}, respectively) (T_3), cowpea alone (6.32 and 6.35 g kg^{-1}, respectively) (T_{13}) and field bean alone (6.20 and 6.22 g kg^{-1}, respectively) (T_{10}). Significantly lower soil organic carbon content during 2017 and 2018 was observed in treatment fodder maize alone (4.85 and 4.85 g kg^{-1}, respectively) (T_9) followed by CA + Fodder maize (5.10 and 5.11 g kg^{-1}, respectively) (T_2) but it was on par with CA + Finger millet (5.77 and 5.79 g kg^{-1}, respectively) (T_1), CA + Niger (5.49 and 5.51 g kg^{-1}, respectively) (T_4) and CA+ Chilli (5.58 and 5.60 g kg^{-1}, respectively) (T_5). The treatments Niger alone (5.16 and 5.18 g kg^{-1}) (T_{11}), Chilli alone (5.42 and 5.45 g kg^{-1}) (T_{12}) and Foxtail millet alone (5.19 and 5.18 g kg^{-1}) (T_{14}) were found to be on par with each other during 2017 and 2018, respectively. Similar trend was observed at all other depths with higher values under custard apple and legume intercropping treatments.

At 15–30 cm depth, significantly higher soil organic carbon content was noticed in treatment CA + Cowpea (6.11 and 6.13 g kg^{-1}) (T_6) recorded followed by CA + Field bean (6.09 and 6.10 g kg^{-1}) (T_3) during 2017 and 2018, respectively. During 2017 and 2018, significantly lower values were recorded in treatment fodder maize alone (4.41 and 4.43 g kg^{-1}, respectively) (T_9) followed by CA + Fodder maize (4.65 and 4.66 g kg^{-1}, respectively) (T_2). At 30–60 and 60–90 cm depth, significantly higher soil organic carbon content during 2017 and 2018 was maintained under CA + Cowpea (T_6) followed by CA + Field bean (T_3), Cowpea alone (T_{13}) and Field bean alone (T_{10}). Significantly lower values were recorded under Fodder maize alone (T_9) and CA + Fodder maize (T_2) treatments.

Pooled analysis of two years (2017 and 2018) experimental data revealed that there was significant difference among the treatments with respect to the organic carbon content of soil. Here, it is emphasized that the variations in organic carbon content in different treatments of the present study were primarily due to differential C inputs from left over root biomass. At 0–15 cm soil depth treatment CA + Cowpea (6.57 g kg^{-1}) (T_6) maintained significantly higher organic carbon content followed by CA + Field bean

(6.49 g kg^{-1}) (T_3), Cowpea alone (6.34 g kg^{-1}) (T_{13}) and Field bean alone (6.21 g kg^{-1}) (T_{10}). Cowpea and field bean being leguminous deep–rooted crops has higher root C–input and higher addition of crop residue. Besides this, a part of legume root is usually slowly decomposable and thereby enrich soil organic carbon. These findings are in accordance with Ramesh and Chandrasekaran (2004) who reported that mungbean crops enriched soil carbon pools. The treatments CA + Finger millet (5.78 g kg^{-1}) (T_1), CA + Niger (5.50 g kg^{-1}) (T_4), CA + Chilli (5.59 g kg^{-1}) (T_5), CA + Foxtail millet (5.37 g kg^{-1}) (T_7), Finger millet alone (5.57 g kg^{-1}) (T_8), Niger alone (5.17 g kg^{-1}) (T_{11}) and Chilli alone (5.44 g kg^{-1}) (T_{12}) were found on par with each other. Significantly lower organic carbon content was recorded in treatment T_9 (Fodder maize alone) (4.85 g kg^{-1}) followed by T_2 (CA + Fodder maize) (5.11 g kg^{-1}) at 0–15 cm depth of soil. But it was on par with Foxtail millet alone (5.19 g kg^{-1}) (T_{14}) and Custard apple alone (5.18 g kg^{-1}) (T_{15}). Generally, it was observed that the intercropping systems maintained a higher organic carbon content in soil than the sole cropping systems. The increased organic carbon content under custard apple based intercropping systems might be due to the increased quantity of plant residues addition through litter fall and higher root biomass from both trees and agriculture crops and reduced soil disturbances. The leaf litter added under custard apple based intercropping systems also acts as mulch, cooling soil surface and reducing soil C oxidation. But under sole cropping system due to direct exposer of soil to sunlight increases the oxidation loss of organic carbon. Hence, these maintained lower organic carbon level in soil. Similar results were also reported by Liao and Boutton (2008).

Pooled analysis revealed that at 15–30, 30–60 and 60–90 cm soil depth, significantly higher organic carbon content was maintained under treatment T_6 (CA + Cowpea) (6.12, 4.16 and 3.13 g kg^{-1}, respectively) followed by T_3 (CA + Field bean) (6.10, 4.15 and 2.85 g kg^{-1}, respectively). Significantly lower organic carbon was recorded in treatment T_9 (Fodder maize alone) (4.42, 2.73 and 1.95 g kg^{-1}) followed by T_2 (CA + Fodder maize) (4.66, 2.91 and 2.20 g kg^{-1}) at 15–30, 30–60 and 60–90 cm depth of soil, respectively. Irrespective of treatments, organic carbon content was decreased with increase in soil depth. The decrease in organic carbon status with depth might be due to

the fact that most of the litter fall and organic matter addition occurs on the surface and very little is incorporated in deeper layers except for addition of C through the decomposing plant roots. Therefore, the build up of soil organic carbon content was more in the surface layer due to more addition of organic matter, root biomass, root exudates and it decreased with depth (Kaur *et al.,* 2000, Brar *et al.,* 2013). The presence of organic carbon content even at lower depths of soil might be due to the downward movement of soluble OM originating from top soil (Chantigny, 2003).

4.4.2 Effect of custard apple based agri–horticulture system on soil inorganic carbon content at different depths

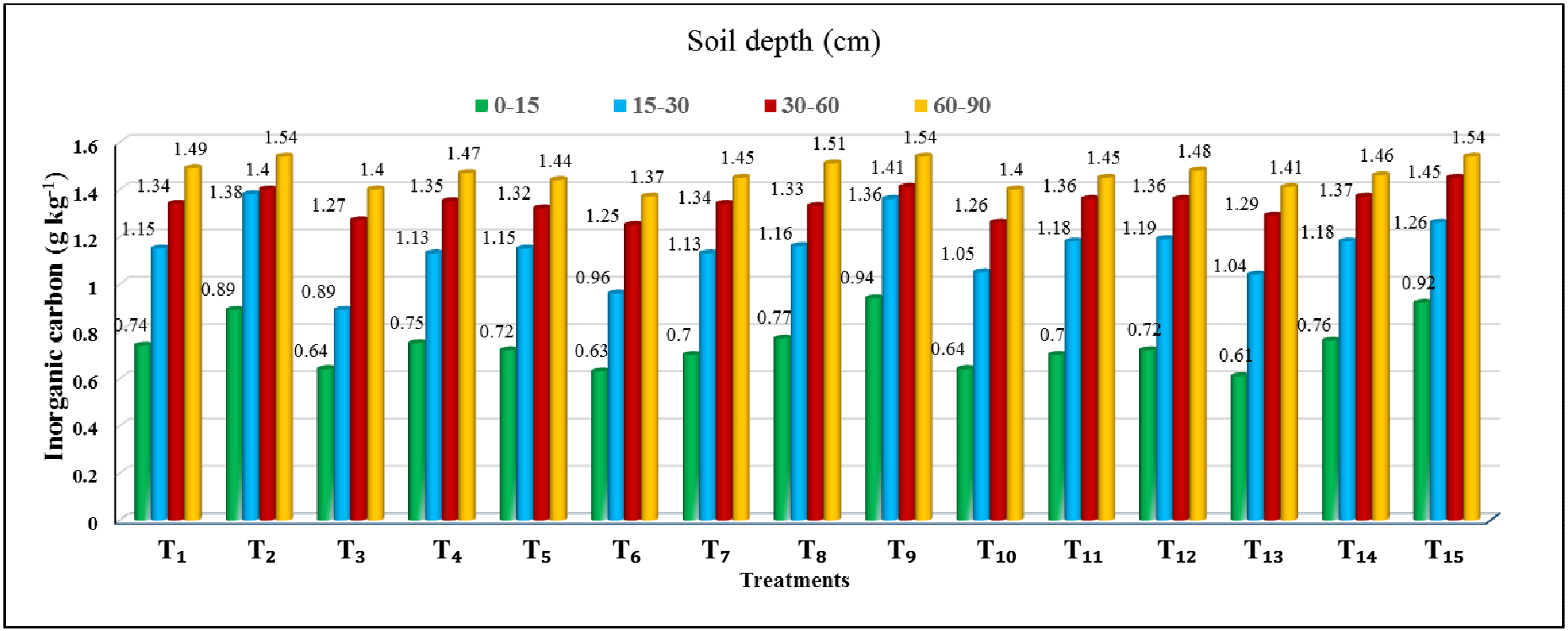
Inorganic forms of carbon are generally derived from soil parent material. Inorganic carbon forms are present in soils typically as carbonates especially, as calcium carbonate. Under custard apple based agri–horticulture system, inorganic carbon content of soil varied significantly among the treatments and the data are presented in Table 4.10 and Figure 4.2.

During 2017 and 2018 soil inorganic carbon content showed a significant difference among the different treatments at 0–15 and 15–30 cm depth and it was found lower values at surface soil and increased with increase in soil depth. At 0–15 cm soil depth, significantly higher soil inorganic carbon content during 2017 and 2018 was observed in treatment fodder maize alone (0.92 and 0.95 g kg^{-1}, respectively) (T_9) followed by Custard apple alone (0.90 and 0.93 g kg^{-1}, respectively) (T_{15}) and CA + Fodder maize (0.89 and 0.88 g kg^{-1}, respectively) (T_2). The treatments CA + Finger millet (0.73 and 0.75 g kg^{-1}, respectively) (T_1), CA + Niger (0.74 and 0.76 g kg^{-1}, respectively) (T_4), CA+ Chilli (0.70 and 0.73 g kg^{-1}, respectively) (T_5) and CA + Foxtail millet (0.71 and 0.69 g kg^{-1}, respectively) (T_7) were found to be on par with each other. Significantly lower soil inorganic carbon was noticed during 2017 and 2018 recorded in Cowpea alone (0.62 and 0.60 g kg^{-1}, respectively) (T_{13}) followed by CA + Cowpea (0.63 and 0.62 g kg^{-1}, respectively) (T_6), CA + Field bean (0.63 and 0.64 g kg^{-1}, respectively) (T_3) and field bean alone (0.65 and 0.63 g kg^{-1}, respectively) (T_{10}). Similar trend was observed at all other depths with higher values under custard apple and fodder maize intercropping treatments.

Table 4.10: Soil inorganic carbon content (g kg^{-1}) at different depths as influenced by custard apple based agri–horticulture system after harvest of crops during 2017 and 2018

Treatments	Soil depth (cm)											
	0-15			15-30			30-60			60-90		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1: CA + Finger millet	0.73	0.75	0.74	1.14	1.15	1.15	1.33	1.34	1.34	1.48	1.49	1.49
T_2: CA + Fodder maize	0.89	0.88	0.89	1.36	1.39	1.38	1.39	1.41	1.40	1.55	1.53	1.54
T_3: CA + Field bean	0.63	0.64	0.64	0.90	0.88	0.89	1.26	1.28	1.27	1.39	1.40	1.40
T_4: CA + Niger	0.74	0.76	0.75	1.11	1.14	1.13	1.35	1.35	1.35	1.46	1.48	1.47
T_5: CA + Chilli	0.70	0.73	0.72	1.15	1.14	1.15	1.31	1.33	1.32	1.44	1.44	1.44
T_6: CA + Cowpea	0.63	0.62	0.63	0.95	0.96	0.96	1.25	1.24	1.25	1.37	1.37	1.37
T_7: CA + Foxtail millet	0.71	0.69	0.70	1.13	1.13	1.13	1.35	1.33	1.34	1.46	1.44	1.45
T_8: Finger millet alone	0.76	0.78	0.77	1.15	1.16	1.16	1.32	1.35	1.33	1.50	1.52	1.51
T_9: Fodder maize alone	0.92	0.95	0.94	1.35	1.37	1.36	1.41	1.40	1.41	1.56	1.53	1.54
T_{10}: Field bean alone	0.65	0.63	0.64	1.03	1.06	1.05	1.26	1.26	1.26	1.39	1.40	1.40
T_{11}: Niger alone	0.70	0.70	0.70	1.16	1.19	1.18	1.37	1.35	1.36	1.45	1.44	1.45
T_{12}: Chilli alone	0.71	0.72	0.72	1.18	1.20	1.19	1.35	1.36	1.36	1.47	1.49	1.48
T_{13}: Cowpea alone	0.62	0.60	0.61	1.03	1.04	1.04	1.28	1.30	1.29	1.40	1.42	1.41
T_{14}: Foxtail millet alone	0.75	0.77	0.76	1.17	1.19	1.18	1.36	1.37	1.37	1.46	1.45	1.46
T_{15}: Custard apple alone	0.90	0.93	0.92	1.24	1.27	1.26	1.43	1.46	1.45	1.54	1.55	1.54
S.Em ±	**0.04**	**0.04**	**0.04**	**0.06**	**0.06**	**0.06**	**0.07**	**0.07**	**0.07**	**0.07**	**0.08**	**0.08**
CD @ 5 %	**0.11**	**0.13**	**0.12**	**0.18**	**0.16**	**0.17**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Note: CA–Custard apple



T_1: CA + Finger millet
T_2: CA + Fodder maize
T_3: CA + Field bean
T_4: CA + Niger
T_5: CA + Chilli
T_6: CA + Cowpea
T_7: CA + Foxtail millet
T_8: Finger millet alone
T_9: Fodder maize alone
T_{10}: Field bean alone
T_{11}: Niger alone
T_{12}: Chilli alone
T_{13}: Cowpea alone
T_{14}: Foxtail millet alone
T_{15}: Custard apple alone

Fig. 4.2: Inorganic carbon content (g kg^{-1}) in soil at different depths as influenced by custard apple based agri-horticulture system after harvest of crops

With increase in soil depth, it was observed that the soil inorganic carbon content increased. At 15–30 cm depth, significantly higher soil inorganic carbon content was noticed in treatment CA + Fodder maize (T_2) (1.36 and 1.39 g kg^{-1}) followed by Fodder maize alone (T_9) (1.35 and 1.37 g kg^{-1}) during 2017 and 2018, respectively. Significantly lower values were recorded in treatment CA + Field bean (0.90 and 0.88 g kg^{-1}) (T_3) followed by CA + Cowpea (0.95 and 0.96 g kg^{-1}) (T_6) during 2017 and 2018, respectively. The soil inorganic carbon content was found to be non–significant among different treatments during 2017 and 2018 at 30–60 and 60–90 cm soil depth.

Pooled analysis results showed that at 0–15 cm soil depth, the inorganic carbon content was significantly higher in treatment T_9 (Fodder maize alone) (0.94 g kg^{-1}) followed by Custard apple alone (0.92 g kg^{-1}) (T_{15}) and T_2 (CA + Fodder maize) (0.89 g kg^{-1}). The inorganic carbon content at 0–15 cm depth was found to be non–significant among the treatments T_{11} (Niger alone) (0.70 g kg^{-1}), T_{12} (Chilli alone) (0.72 g kg^{-1}), T_{14} (Foxtail millet alone) (0.76 g kg^{-1}), T_4 (CA + Niger) (0.75 g kg^{-1}), T_5 (CA + chilli) (0.72 g kg^{-1}) and T_7 (CA + Foxtail millet) (0.70 g kg^{-1}). Significantly lower inorganic carbon values were recorded in treatment T_{13} (Cowpea alone) (0.61 g kg^{-1}) followed by T_6 (CA + Cowpea) (0.63 g kg^{-1}), T_{10} (Field bean alone) (0.64 g kg^{-1}) and T_3 (CA + Field bean) (0.64 g kg^{-1}). This might be attributed to the production of organic acids during organic matter decomposition which lead to dissolution as well as decalcification process in which the inorganic carbon will be leached to lower layers increases the inorganic carbon content at lower layers of soil (Sartori *et al.,* 2007). Wei Zhao *et al.* (2016) reported that increase in microbial activity (thus more CO_2 production) leads to decrease in soil inorganic carbon in soil, especially in surface soil. Thus, quantities of soil microbial biomass and soil organic carbon will determine the formation or the process of dissolution of soil inorganic carbon and precipitation of soil inorganic carbon.

At 30–60 and 60–90 cm soil depth, the inorganic carbon content was found non–significant among the treatments. The inorganic carbon content at different depths of soil varied because of the changes in soil bulk density, soil pH and proposed release as CO_2 can mainly occur in the rooting zone, which has significant influence on the SIC storage

(Weiguo Liu *et al.,* 2014). The presence of higher inorganic carbon at lower depths of soil profile might be due to inorganic carbon derived from parent material.

4.4.3 Effect of custard apple based agri–horticulture system on soil microbial carbon content at different depths

The microbial carbon is one of the fractions of soil organic carbon which constitutes a very small portion but considered as a good indicator of soil health. The data on soil microbial carbon among different treatments and at different depths of soil varied significantly due to custard apple based agri–horticulture system (Table 4.11 and Figure 4.3).

The microbial carbon is an important component of soil organic matter that regulates the transformation and storage of nutrients. The soil microbial carbon regulates soil organic matter transformations and is considered to be the chief component of the active pool of soil organic matter. Although microbial carbon content in soil represent a small fraction (*i.e.* about 1 to 5% of total organic carbon), variation in this pool due to management and cropping systems indicate about the quality of soil, because the turn–over of soil organic matter is controlled by this pool which can provide an effective early warning of the improvement or deterioration of soil quality as a result of different management practices (Powlson *et al.,* 1987).

Among the different treatments, the soil microbial carbon significantly varied at all depths during 2017 and 2018. At 0–15 cm soil depth, the treatment T_6 (CA + Cowpea) (293.17 and 295.83 mg kg^{-1}) recorded significantly higher soil microbial carbon during 2017 and 2018, respectively. However, it was on par with the treatment T_3 (CA + Field bean) (285.13 and 289.58 mg kg^{-1}), T_{13} (Cowpea alone) (284.49 and 288.96 mg kg^{-1}) and T_{10} (Field bean alone) (273.18 and 280.79 mg kg^{-1}) during 2017 and 2018, respectively. Significantly lower soil microbial carbon was noticed in treatment T_9 (Fodder maize alone) (201.49 and 213.55 mg kg^{-1}) followed by T_2 (CA + Fodder maize) (215.64 and 218.39 mg kg^{-1}) during 2017 and 2018, respectively. Similar trend was noticed at all other soil depths.

Table 4.11: Soil microbial carbon content (mg kg^{-1}) at different depths as influenced by custard apple based agri–horticulture system after harvest of crops during 2017 and 2018

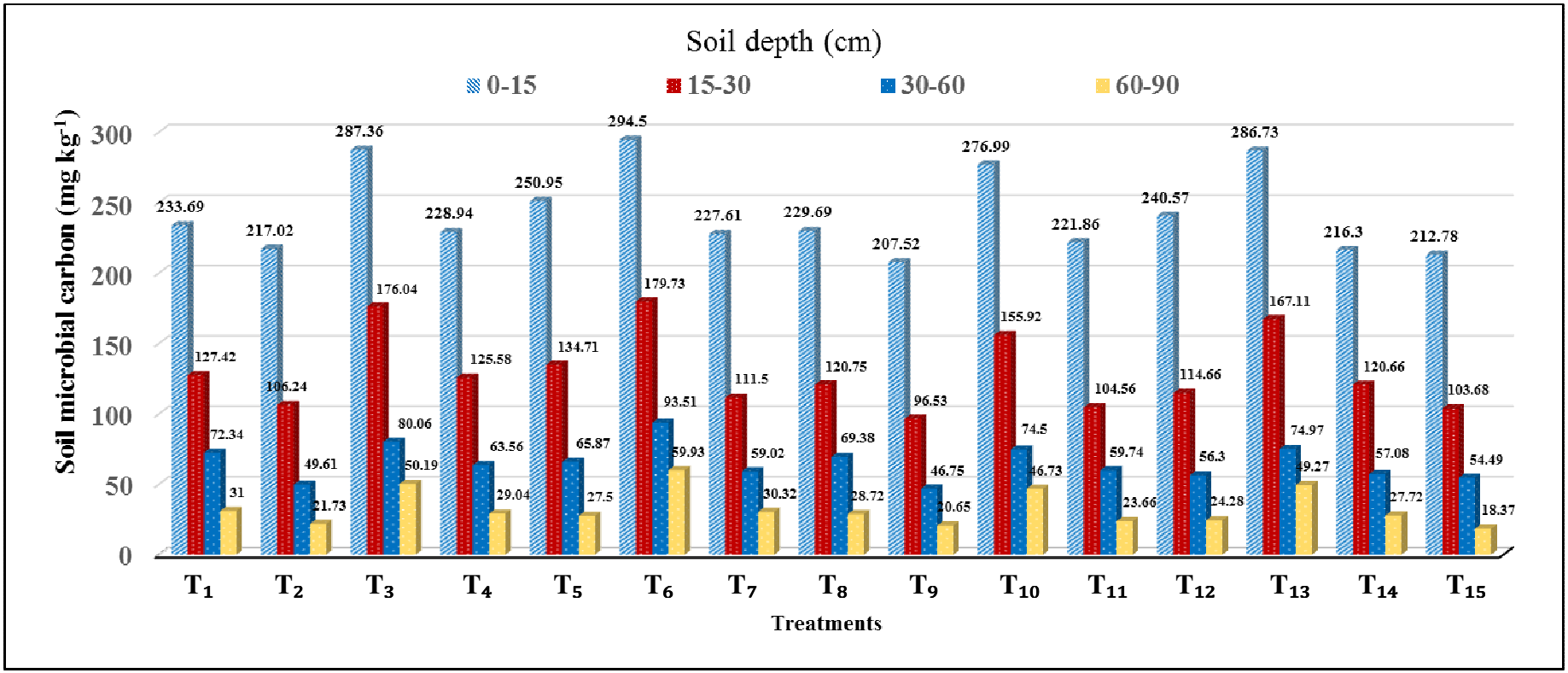
Treatments	Soil depth (cm)											
	0-15			15-30			30-60			60-90		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1: CA + Finger millet	231.25	236.13	233.69	126.62	128.22	127.42	70.24	74.45	72.34	30.93	31.08	31.00
T_2: CA + Fodder maize	215.64	218.39	217.02	108.06	104.42	106.24	48.03	51.19	49.61	22.63	20.82	21.73
T_3: CA + Field bean	285.13	289.58	287.36	172.63	179.45	176.04	80.27	79.86	80.06	50.95	49.42	50.19
T_4: CA + Niger	227.49	230.39	228.94	125.08	126.08	125.58	62.81	64.30	63.56	28.61	29.47	29.04
T_5: CA + Chilli	251.48	250.42	250.95	132.35	137.06	134.71	63.65	68.10	65.87	28.06	26.94	27.50
T_6: CA + Cowpea	293.17	295.83	294.50	178.27	181.18	179.73	91.23	95.79	93.51	58.47	61.39	59.93
T_7: CA + Foxtail millet	224.86	230.36	227.61	112.62	110.37	111.50	59.62	58.43	59.02	30.62	30.01	30.32
T_8: Finger millet alone	228.32	231.05	229.69	121.09	120.40	120.75	68.62	70.13	69.38	29.91	27.52	28.72
T_9: Fodder maize alone	201.49	213.55	207.52	94.63	98.42	96.53	45.83	47.66	46.75	20.41	20.88	20.65
T_{10}: Field bean alone	273.18	280.79	276.99	150.43	161.40	155.92	72.68	76.32	74.50	45.60	47.86	46.73
T_{11}: Niger alone	220.64	223.08	221.86	105.85	103.26	104.56	58.68	60.79	59.74	22.86	24.46	23.66
T_{12}: Chilli alone	239.34	241.80	240.57	114.82	114.49	114.66	55.81	56.79	56.30	24.37	24.18	24.28
T_{13}: Cowpea alone	284.49	288.96	286.73	165.08	169.13	167.11	73.06	76.87	74.97	49.00	49.53	49.27
T_{14}: Foxtail millet alone	216.63	215.96	216.30	118.02	123.30	120.66	57.23	56.94	57.08	27.26	28.17	27.72
T_{15}: Custard apple alone	210.57	214.99	212.78	101.64	105.71	103.68	53.42	55.56	54.49	18.01	18.73	18.37
S.Em ±	**11.56**	**12.42**	**11.90**	**7.22**	**6.35**	**6.70**	**3.79**	**3.19**	**3.42**	**1.49**	**1.62**	**1.53**
CD @ 5 %	**33.50**	**35.97**	**34.48**	**20.93**	**18.40**	**19.40**	**10.97**	**9.25**	**9.92**	**4.31**	**4.70**	**4.43**

Note: CA–Custard apple

Irrespective of treatments the content of soil microbial carbon decreased significantly with depths. During 2017 and 2018, the higher soil microbial carbon was maintained under treatment T_6 (CA + Cowpea) at 15–30 cm (178.27 and 181.18 mg kg^{-1}, respectively), 30–60 cm (91.23 and 95.79 mg kg^{-1}, respectively) and 60–90 cm (58.47 and 61.39 mg kg^{-1}, respectively) depths of soil followed by T_3 (CA + Field bean) at 15–30 cm (172.63 and 179.45 mg kg^{-1}, respectively), 30–60 cm (80.27 and 79.86 mg kg^{-1}, respectively) and 60–90 cm (50.95 and 49.42 mg kg^{-1}, respectively). Significantly lower microbial carbon was recorded in treatment T_9 (Fodder maize alone) at 15–30 cm (94.63 and 98.42 mg kg^{-1}, respectively), 30–60 cm (45.83 and 47.66 mg kg^{-1}, respectively) and 60–90 cm (20.41 and 20.88 mg kg^{-1}, respectively) during 2017 and 2018.

The pooled data of 2017 and 2018 experiment revealed that there was a significant difference among the treatments at all depths. At 0–15 cm depth, significantly higher soil microbial carbon was recorded in treatment CA + Cowpea (T_6) (294.50 mg kg^{-1}) which was on par with T_3 (CA + Field bean) (287.36 mg kg^{-1}), T_{13} (Cowpea alone) (286.73 mg kg^{-1}) and T_{10} (Field bean) (276.99 mg kg^{-1}). Leguminous crops are effective in improving soil fertility, differential accumulation of organic carbon, nitrogen and inorganic nutrients in topsoil under intercropping systems as well as accumulation of inorganic nutrients tend to increase soil microbial activities there by increasing the microbial carbon. These results are in consonance with the findings of Patil *et al.* (2010); Singh *et al*. (2010) and Hema Singh *et al*. (2011). The soil microbial carbon was found on par among treatments like CA + Finger millet (233.69 mg kg^{-1}) (T_1), CA + Niger (228.94 mg kg^{-1}) (T_4), CA + Chilli (250.95 mg kg^{-1}) (T_5), CA + Foxtail millet (227.61 mg kg^{-1}) (T_7), Finger millet alone (229.69 mg kg^{-1}) (T_8), Niger alone (221.86 mg kg^{-1}) (T_{11}) and Chilli alone (240.57 mg kg^{-1}) (T_{12}). The treatment T_9 (Fodder maize alone) (207.52 mg kg^{-1}) recorded significantly lower soil microbial carbon content at 0–15 cm depth. But it was on par with T_2 (CA + Fodder maize) (217.02 mg kg^{-1}), T_{14} (Foxtail millet alone) (216.30 mg kg^{-1}) and T_{15} (Custard apple alone) (212.78 mg kg^{-1}) treatments. Similar trend was observed at all depths.

According to pooled data, the soil microbial carbon content at 15–30, 30–60 and 60–90 cm depth of soil was found significantly higher in treatment T_6 (CA + Cowpea)



T_1: CA + Finger millet
T_2: CA + Fodder maize
T_3: CA + Field bean
T_4: CA + Niger
T_5: CA + Chilli
T_6: CA + Cowpea
T_7: CA + Foxtail millet
T_8: Finger millet alone
T_9: Fodder maize alone
T_{10}: Field bean alone
T_{11}: Niger alone
T_{12}: Chilli alone
T_{13}: Cowpea alone
T_{14}: Foxtail millet alone
T_{15}: Custard apple alone

Fig. 4.3: Soil microbial carbon content (mg kg^{-1}) at different depths as influenced by custard apple based agri-horticulture system after harvest of crops

(179.73, 93.51 and 59.93 mg kg^{-1}, respectively) and T_3 (CA + Field bean) (176.04, 80.06 and 50.19 mg kg^{-1}, respectively). Significantly lower soil microbial carbon content at 15–30, 30–60 and 60–90 cm depth of soil was found in treatment T_9 (Fodder maize alone) (96.53, 46.75 and 20.65 mg kg^{-1}, respectively) followed by T_2 (CA + Fodder maize) (106.24, 49.61 and 21.73 mg kg^{-1}, respectively). Irrespective of the treatments, the soil microbial carbon content decreased with increase in soil depth which might be due to decreased organic carbon content in soil. However, the downward movement of soluble OM originating from top soil plays an important role in sustaining subsoil microbial activity (Chantigny, 2003) which in turn sustains microbial biomass carbon. The surface soil exhibited higher MBC content compared to lower soil depths primarily because of addition of left–over crop residues and root biomass into the topsoil. This view is consistent with the observation of Hao *et al.* (2008) who reported that the microbial biomass was considerably greater in soils receiving FYM along with NPK fertilizer than in plots receiving merely NPK in three subtropical paddy soils. It is suggested that the greater biochemical recalcitrance of root litter might have also increased the MBC contents in soil depending root biomass produced. However, the MBC content was lower with increasing depth due to the fact that roots are unable to extend to lower depths (Puget and Drinkwater, 2001). The main source of MBC in subsurface soil was left over root biomass and increased microbial biomass debris. The pooled data revealed that the soil microbial carbon content was higher under intercropping systems compared to their respective sole crops. Intercropping systems maintained a positive and significant correlation with abiotic variables *i.e.* soil moisture, soil temperature, rainfall, mean air temperature and relative humidity thereby favouring suitable environment for the growth and activity of micro flora, macro fauna and microbial biomass C and N as reported by Srinivasan *et al.* (2010) and Paudel *et al.* (2011).

4.4.4 Effect of custard apple based agri–horticulture system on water soluble carbon content at different depths

Water soluble carbon (WSC) is believed to be derived from plant roots, litter and soil humus and is a labile substrate for microbial activity (Kalbitz *et al*., 2000). WSC is a fraction of easily degradable pool of organic matter and is considered as a stability

indicator of SOM. The results pertaining to effect of custard apple based agri–horticulture system on WSC are presented in Table 4.12 and Figure 4.4. There was a significant variation in WSC among different treatments in surface as well as in subsurface soil samples.

At 0–15 cm depth, significantly higher WSC was noticed in treatment T_6 (CA + Cowpea) (49.96 and 55.46 mg kg^{-1}) followed by T_3 (CA + Field bean) (47.38 and 52.96 mg kg^{-1}), T_{13} (Cowpea alone) (45.85 and 49.47 mg kg^{-1}) and T_{10} (Field bean) (44.81 and 50.12 mg kg^{-1}) during 2017 and 2018, respectively. Irrespective of depths these treatments showed significantly higher build up of WSC as compared to rest of the treatments. During 2017 and 2018, significantly lower WSC was recorded in treatment T_9 (Fodder maize alone) (29.61 and 30.79 mg kg^{-1}, respectively) followed by T_2 (CA + Fodder maize alone) (33.92 and 34.21 mg kg^{-1}, respectively). Whereas, there was no significant difference between the treatments T_1 (CA + Finger millet) (39.25 and 43.61 mg kg^{-1}), T_4 (CA + Niger) (36.27 and 38.82 mg kg^{-1}), T_7 (CA + Foxtail millet) (37.60 and 39.85 mg kg^{-1}) and T_8 (Finger millet alone) (37.32 and 38.33 mg kg^{-1}) during 2017 and 2018, respectively. During 2017 and 2018, at 15–30, 30–60 and 60–90 cm depth the higher WSC was observed in treatment with legume crops with highest in T_6 (CA + Cowpea) (37.01 and 41.86, 24.33 and 25.55, 17.38 and 18.25 mg kg^{-1}, respectively) followed by T_3 (CA + Field bean) (35.28 and 39.22, 23.17 and 25.47, 16.68 and 17.18 mg kg^{-1}, respectively). During 2017 and 2018 significantly lower WSC was recorded in treatment T_9 (Fodder maize alone) (24.32 and 25.37, 16.03 and 14.75, 12.29 and 11.31 mg kg^{-1}) at 15–30, 30–60 and 60–90 cm depth, respectively. The differences in concentration of WSC in soil under different treatments with different crops may be because of different root exudation pattern, amount and the type of carbon input to the soil.

Pooled analysis of 2017 and 2018 experimental data suggests that at 0–15 cm depth the treatment T_6 (CA + Cowpea) (52.71 mg kg^{-1}) recorded significantly higher WSC followed by T_3 (CA + Field bean) (50.17 mg kg^{-1}), T_{13} (Cowpea alone) (47.66 mg kg^{-1}) and T_{10} (Field bean alone) (47.47 mg kg^{-1}). The increased WSC under custard apple-legume cropping systems might be due to increased organic matter by the addition

Table 4.12: Water soluble carbon content (mg kg^{-1}) in soil at different depths as influenced by custard apple based agri–horticulture system after harvest of crops during 2017 and 2018

Treatments	Soil depth (cm)											
	0-15			15-30			30-60			60-90		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1: CA + Finger millet	39.25	43.61	41.43	27.30	30.29	28.80	18.32	19.42	18.87	14.69	15.57	15.13
T_2: CA + Fodder maize	33.92	34.21	34.07	24.32	25.37	24.85	16.03	14.75	15.39	12.29	11.31	11.80
T_3: CA + Field bean	47.38	52.96	50.17	35.28	39.22	37.25	23.17	25.47	24.32	16.68	17.18	16.93
T_4: CA + Niger	36.27	38.82	37.55	25.66	26.63	26.14	17.28	16.59	16.94	14.32	15.75	15.04
T_5: CA + Chilli	36.48	37.02	36.75	26.08	28.04	27.06	18.01	20.29	19.15	14.56	13.98	14.27
T_6: CA + Cowpea	49.96	55.46	52.71	37.01	41.86	39.44	24.33	25.55	24.94	17.38	18.25	17.82
T_7: CA + Foxtail millet	37.60	39.85	38.73	25.67	25.16	25.42	16.92	16.58	16.75	13.01	12.75	12.88
T_8: Finger millet alone	37.32	38.33	37.82	26.08	28.99	27.54	17.81	16.39	17.10	14.31	15.17	14.74
T_9: Fodder maize alone	29.61	30.79	30.20	21.63	22.50	22.07	12.48	13.78	13.13	11.63	12.10	11.87
T_{10}: Field bean alone	44.81	50.12	47.47	32.92	35.94	34.43	20.68	19.44	20.06	15.72	16.78	16.25
T_{11}: Niger alone	34.32	36.72	35.52	25.53	27.32	26.43	16.18	17.31	16.75	13.43	14.37	13.90
T_{12}: Chilli alone	35.18	42.01	38.59	25.31	25.03	25.17	17.21	18.66	17.93	14.26	12.98	13.62
T_{13}: Cowpea alone	45.85	49.47	47.66	33.57	36.56	35.07	22.62	21.94	22.28	16.66	17.16	16.91
T_{14}: Foxtail millet alone	35.63	34.20	34.92	23.04	22.12	22.58	17.06	16.38	16.72	13.31	12.78	13.05
T_{15}: Custard apple alone	33.10	36.42	34.76	25.67	26.70	26.19	16.96	17.64	17.30	13.17	13.70	13.44
S.Em ±	**2.24**	**1.98**	**2.07**	**1.59**	**1.56**	**1.53**	**0.88**	**0.91**	**0.90**	**0.68**	**0.70**	**0.69**
CD @ 5 %	**6.50**	**5.74**	**5.99**	**4.62**	**4.52**	**4.43**	**2.56**	**2.63**	**2.59**	**1.96**	**2.04**	**1.99**

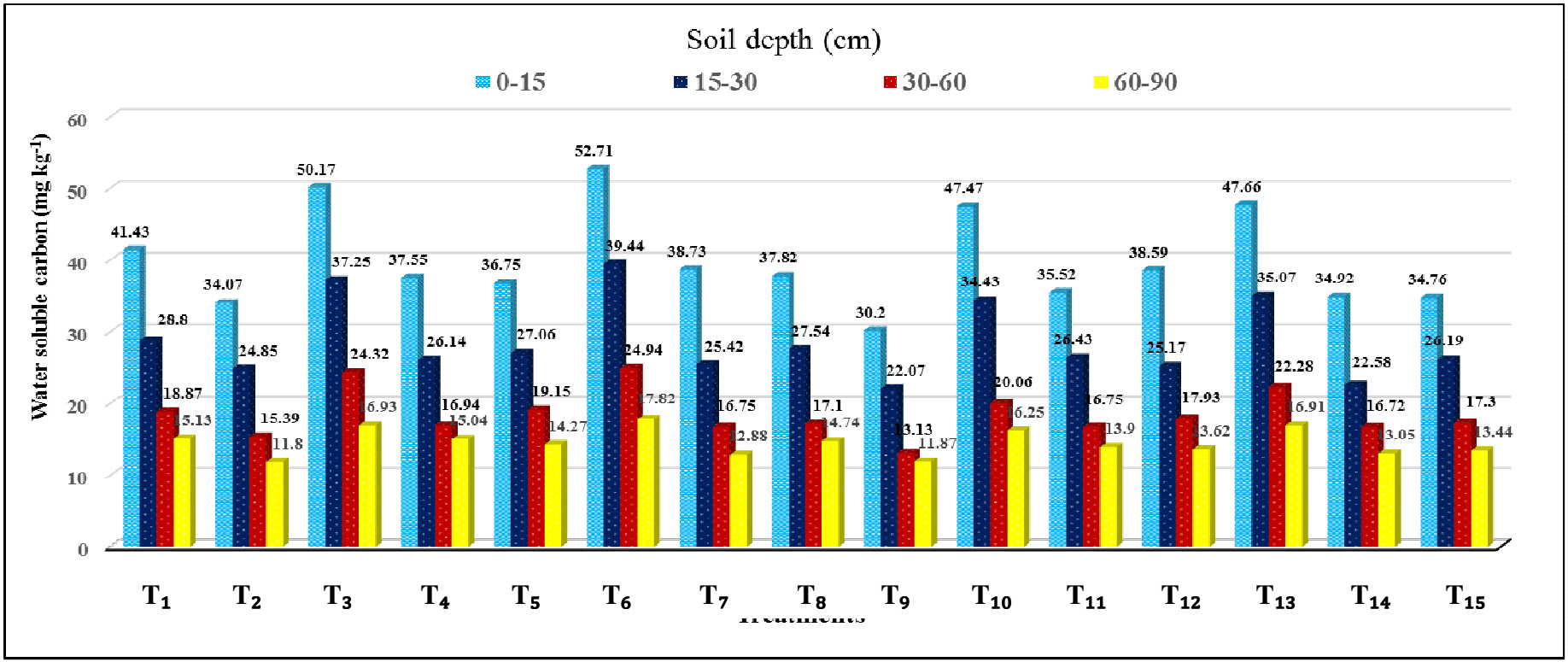
Note: CA–Custard apple

of crop residue and litter fall. Significantly lower WSC was recorded in treatment Fodder maize alone (T_9) (30.20 mg kg^{-1}) followed by CA + Fodder maize (T_2) (34.07 mg kg^{-1}) and Custard apple alone (34.76 mg kg^{-1}). This might be due decreased organic carbon content in soil. However, the WSC content was non–significant among the treatments CA + Finger millet (41.42 mg kg^{-1}) (T_1), CA + Niger (37.55 mg kg^{-1}) (T_4), CA + Chilli (36.75 mg kg^{-1}) (T_5), CA + Foxtail millet (38.73 mg kg^{-1}) (T_7), Finger millet alone (37.82 mg kg^{-1}) (T_8), and Chilli alone (38.59 mg kg^{-1}) (T_{12}). Similar trend was observed at all depths of soil but the content of WSC was found decreased with increased soil depth. WSC in subsurface soils may be a result of decomposition of crop residues or translocation from surface soil (Dou *et al.*, 2007). Several field studies have shown that concentration and fluxes of WSC in soil solution decreased significantly with soil depth (Kalbitz *et al.*, 2000). It was also observed that there was no significant difference among intercrops and sole crops of respective crops but higher values were maintained under intercropping systems. This might be due to the loss of organic carbon in sole crops with cultivation could be attributed to the repeated exposure and subsequent aeration and oxidation of light fraction of organic carbon associated with macroaggregates and macro-pores (Shephered *et al.,* 2001).

Pooled data revealed that the WSC content at 15–30, 30–60 and 60–90 cm depth of soil was found to be higher in treatment CA + Cowpea (T_6) (39.44, 24.94 and 17.82 mg kg^{-1}, respectively) followed by CA + Field bean (T_3) (37.25, 24.32 and 16.93 mg kg^{-1}, respectively). Significantly lower WSC was maintained under treatment Fodder maize alone (T_9) (22.07, 13.13 and 11.87 mg kg^{-1}) and CA + Fodder maize (T_2) (24.85, 15.39 and 11.80 mg kg^{-1}) at 15–30, 30–60 and 60–90 cm depth, respectively.

4.4.5 Effect of custard apple based agri–horticulture system on active/labile carbon content at different depths

Labile carbon represents an easily decomposable fraction of soil organic matter that decomposes within a few weeks or months. Higher level of labile carbon indicates greater turnover rate of organic matter and higher availability of other nutrients also. The labile carbon is mainly characterized by rapid mineralization due to its labile nature and



T_1: CA + Finger millet
T_2: CA + Fodder maize
T_3: CA + Field bean
T_4: CA + Niger
T_5: CA + Chilli
T_6: CA + Cowpea
T_7: CA + Foxtail millet
T_8: Finger millet alone
T_9: Fodder maize alone
T_{10}: Field bean alone
T_{11}: Niger alone
T_{12}: Chilli alone
T_{13}: Cowpea alone
T_{14}: Foxtail millet alone
T_{15}: Custard apple alone

Fig. 4.4: Water soluble carbon content (mg kg^{-1}) in soil at different depths as influenced by custard apple based agri-horticulture system after harvest of crops

lack of protection by soil colloids (Turchenek and Oades 1979). Custard apple based agri–horticulture system significantly influenced the active/labile carbon content of soil in surface as well as its distribution in lower depths. The data pertaining to profile distribution of active/labile carbon content in surface and subsurface soil has been presented in Table 4.13 and Figure 4.5.

At 0–15 cm depth of soil, significantly higher active/labile carbon content was maintained under treatment T_6 (CA + Cowpea) (657.12 and 654.98 mg kg^{-1}) which was followed by T_3 (CA + Field bean) (641.53 and 646.29 mg kg^{-1}), T_{13} (Cowpea alone) (640.15 and 643.94 mg kg^{-1}) and T_{10} (Field bean alone) (638.79 and 639.46 mg kg^{-1}) during 2017 and 2018, respectively. Whereas the treatments T_1 (CA + Finger millet) (543.15 and 552.74 mg kg^{-1}), T_4 (CA + Niger) (538.90 and 539.74 mg kg^{-1}), T_5 (CA + Chilli) (522.95 and 525.03 mg kg^{-1}), T_7 (CA + Foxtail millet) (530.53 and 535.92 mg kg^{-1}), T_8 (Finger millet alone) (538.03 and 540.99 mg kg^{-1}), T_{14} (Foxtail millet alone) (517.05 and 516.37 mg kg^{-1}) and T_{15} (Custard apple alone) (527.55 and 530.65 mg kg^{-1}) were found to be non–significant during 2017 and 2018, respectively. Significantly lower active/labile carbon was recorded in treatment T_9 (Fodder maize alone) (468.08 and 474.81 mg kg^{-1}) followed by T_2 (CA + Fodder maize) (485.66 and 491.81 mg kg^{-1}) during 2017 and 2018, respectively. Similar trend was recorded in lower depths of soil.

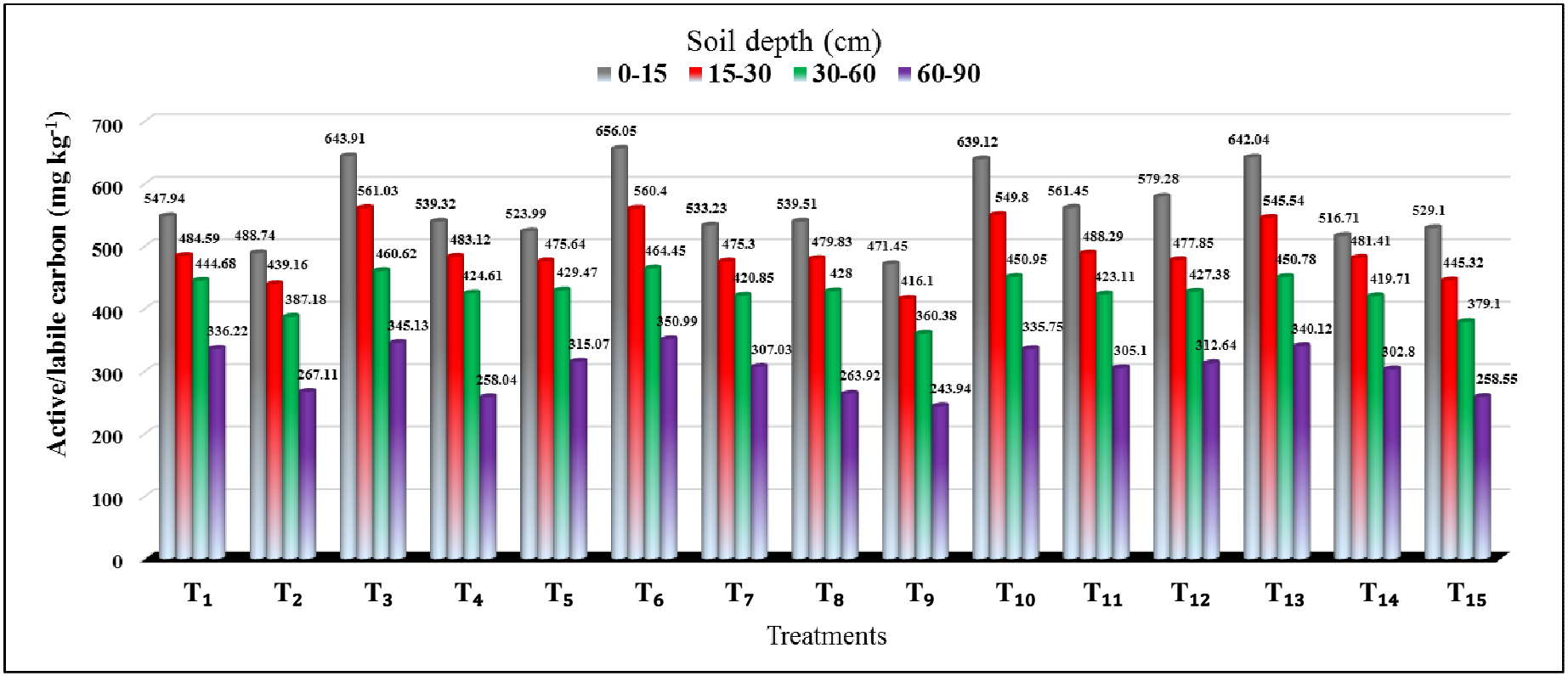
During 2017 and 2018, significantly higher active/labile carbon was maintained under CA + Cowpea (T_6) (556.98 and 563.83, 463.85 and 465.04, 349.26 and 352.72 mg kg^{-1}) followed by CA + Field bean (T_3) (559.93 and 562.13, 460.02 and 461.22, 345.31 and 344.95 mg kg^{-1}) at 15–30, 30–60 and 60–90 cm depth of soil, respectively. Significantly lower values were recorded in treatment T_9 (Fodder maize alone) (412.35 and 419.84, 360.66 and 360.09, 244.06 and 243.82 mg kg^{-1}) at 15–30, 30–60 and 60–90 cm depth of soil, respectively.

Results of the pooled analysis of 2017 and 2018 experimental data suggested that at 0–15 cm depth significantly higher active/labile carbon was found in treatment CA + Cowpea (T_6) (656.05 mg kg^{-1}) followed by T_3 (CA + Field bean) (643.91 mg kg^{-1}), T_{13} (Cowpea alone) (642.04 mg kg^{-1}) and T_{10} (Field bean alone) (639.12 mg kg^{-1}).

Table 4.13: Active/labile carbon content (mg kg^{-1}) in soil at different depths as influenced by custard apple based agri–horticulture system after harvest of crops during 2017 and 2018

Treatments	Soil depth (cm)											
	0-15			15-30			30-60			60-90		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1: CA + Finger millet	543.15	552.74	547.94	482.61	486.57	484.59	443.38	445.98	444.68	335.65	336.79	336.22
T_2: CA + Fodder maize	485.66	491.81	488.74	438.18	440.13	439.16	388.21	386.15	387.18	267.82	266.39	267.11
T_3: CA + Field bean	641.53	646.29	643.91	559.93	562.13	561.03	460.02	461.22	460.62	345.31	344.95	345.13
T_4: CA + Niger	538.90	539.74	539.32	480.22	486.01	483.12	425.63	423.60	424.61	309.22	206.85	258.04
T_5: CA + Chilli	522.95	525.03	523.99	475.65	475.62	475.64	428.54	430.40	429.47	314.35	315.78	315.07
T_6: CA + Cowpea	657.12	654.98	656.05	556.98	563.83	560.40	463.85	465.04	464.45	349.26	352.72	350.99
T_7: CA + Foxtail millet	530.53	535.92	533.23	476.56	474.03	475.30	421.06	420.64	420.85	305.08	308.98	307.03
T_8: Finger millet alone	538.03	540.99	539.51	478.47	481.19	479.83	427.08	428.91	428.00	311.37	216.46	263.92
T_9: Fodder maize alone	468.08	474.81	471.45	412.35	419.84	416.10	360.66	360.09	360.38	244.06	243.82	243.94
T_{10}: Field bean alone	638.79	639.46	639.12	545.67	553.93	549.80	448.92	452.98	450.95	335.82	335.67	335.75
T_{11}: Niger alone	560.34	562.56	561.45	486.75	489.82	488.29	422.81	423.41	423.11	304.45	305.76	305.10
T_{12}: Chilli alone	576.21	582.35	579.28	478.37	477.32	477.85	428.67	426.09	427.38	311.67	313.62	312.64
T_{13}: Cowpea alone	640.15	643.94	642.04	540.14	550.94	545.54	451.04	450.51	450.78	339.71	340.52	340.12
T_{14}: Foxtail millet alone	517.05	516.37	516.71	480.52	482.30	481.41	420.62	418.80	419.71	301.32	304.27	302.80
T_{15}: Custard apple alone	527.55	530.65	529.10	442.47	448.17	445.32	378.53	379.67	379.10	256.42	260.68	258.55
S.Em ±	**29.10**	**27.02**	**27.92**	**22.89**	**23.66**	**23.17**	**20.35**	**19.74**	**19.99**	**14.76**	**15.48**	**15.04**
CD @ 5 %	**84.31**	**78.29**	**80.89**	**66.32**	**68.54**	**67.13**	**58.96**	**57.18**	**57.92**	**42.75**	**44.85**	**43.57**

Note: CA–Custard apple



T_1: CA + Finger millet
T_2: CA + Fodder maize
T_3: CA + Field bean
T_4: CA + Niger
T_5: CA + Chilli
T_6: CA + Cowpea
T_7: CA + Foxtail millet
T_8: Finger millet alone
T_9: Fodder maize alone
T_{10}: Field bean alone
T_{11}: Niger alone
T_{12}: Chilli alone
T_{13}: Cowpea alone
T_{14}: Foxtail millet alone
T_{15}: Custard apple alone

Fig. 4.5: Active/labile carbon content (mg kg^{-1}) in soil at different depths as influenced by custard apple based agri-horticulture system after harvest of crops

The increased active/labile C under custard apple–legume intercropping systems might be due to increased easily oxidizable organic matter addition through crop residue and litter fall. The active/labile carbon content was found to be on par in treatments T_1 (CA + Finger millet) (547.94 mg kg^{-1}), T_5 (CA + Chilli) (523.99 mg kg^{-1}), T_7 (CA + Foxtail millet) (533.23 mg kg^{-1}), T_8 (Finger millet alone) (539.51 mg kg^{-1}), T_{14} (Foxtail millet alone) (516.71 mg kg^{-1}), T_{15} (Custard apple alone) (529.10 mg kg^{-1}) at 0–15 cm depth. Significantly lower active/labile carbon was found in treatment Fodder maize alone (T_9) (471.45 mg kg^{-1}) followed by CA + Fodder maize (T_2) (488.74 mg kg^{-1}). Similar trend was maintained at all depths of soil with higher values in treatments with legume crops. Irrespective of treatments, the active/labile carbon content decreased with increase in depth of soil.

Pooled data revealed that at 15–30, 30–60 and 60–90 cm depth, treatment CA + Cowpea (T_6) (560.40, 464.45 and 350.99 mg kg^{-1}, respectively) maintained higher active/labile carbon content in soil followed by CA + Field bean (T_3) (561.03, 460.62 and 345.13 mg kg^{-1}, respectively). Significantly lower active/labile carbon was recorded in treatment T_9 (Fodder maize alone) (416.10, 360.38 and 243.94 mg kg^{-1}) at 15–30, 30–60 and 60–90 cm depth, respectively. In general, there was a decrease in labile/active carbon concentration with depth, a normal trend since organic carbon also decreased with depth (Danielle *et al.,* 2014). Higher easily oxidizable fractions in surface soil are related to the input of organic carbon coming from the decomposing leaf litter (Gleixner *et al.,* 2001). Generally, with respect to individual crop, higher active/labile carbon was found in intercrops compared to their respective sole crop.

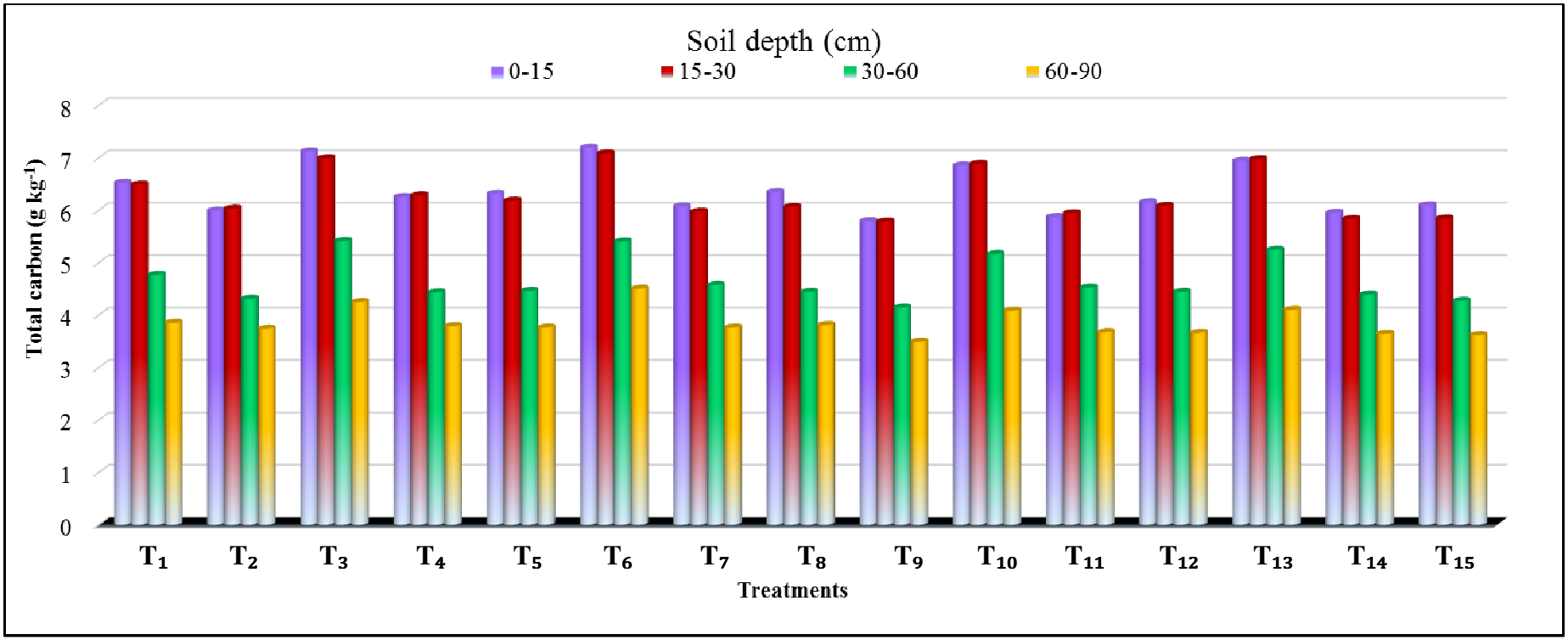
4.4.6 Effect of custard apple based agri–horticulture system on total carbon content of soil at different depths

Total carbon in soil represents the organic carbon plus inorganic carbon in soil. There was a significant difference among the treatments for total carbon content under custard apple based agri–horticulture system and the pertaining data are presented in Table 4.14 and Figure 4.6.

Table 4.14: Total carbon content (g kg^{-1}) in soil at different depths as influenced by custard apple based agri–horticulture system after harvest of crops during 2017 and 2018

Treatments	Soil depth (cm)											
	0-15			15-30			30-60			60-90		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1: CA + Finger millet	6.50	6.55	6.52	6.49	6.49	6.49	4.75	4.79	4.77	3.83	3.87	3.85
T_2: CA + Fodder maize	5.99	5.99	5.99	6.01	6.05	6.03	4.29	4.32	4.31	3.74	3.75	3.74
T_3: CA + Field bean	7.11	7.13	7.12	6.99	6.98	6.99	5.39	5.44	5.41	4.23	4.26	4.25
T_4: CA + Niger	6.23	6.27	6.25	6.27	6.29	6.28	4.42	4.43	4.43	3.77	3.81	3.79
T_5: CA + Chilli	6.28	6.33	6.31	6.17	6.18	6.18	4.43	4.48	4.46	3.76	3.75	3.76
T_6: CA + Cowpea	7.19	7.19	7.19	7.06	7.09	7.08	5.40	5.40	5.40	4.49	4.50	4.50
T_7: CA + Foxtail millet	6.07	6.07	6.07	5.96	5.98	5.97	4.56	4.57	4.57	3.79	3.74	3.76
T_8: Finger millet alone	6.33	6.34	6.34	6.07	6.05	6.06	4.42	4.47	4.44	3.79	3.82	3.81
T_9: Fodder maize alone	5.77	5.80	5.79	5.76	5.80	5.78	4.14	4.13	4.14	3.50	3.48	3.49
T_{10}: Field bean alone	6.85	6.85	6.85	6.87	6.88	6.88	5.15	5.17	5.16	4.07	4.08	4.08
T_{11}: Niger alone	5.86	5.88	5.87	5.92	5.97	5.94	4.53	4.51	4.52	3.66	3.67	3.67
T_{12}: Chilli alone	6.13	6.17	6.15	6.09	6.08	6.08	4.42	4.46	4.44	3.66	3.66	3.66
T_{13}: Cowpea alone	6.94	6.95	6.94	6.98	6.97	6.97	5.22	5.26	5.24	4.10	4.10	4.10
T_{14}: Foxtail millet alone	5.94	5.95	5.95	5.83	5.84	5.83	4.38	4.39	4.39	3.64	3.64	3.64
T_{15}: Custard apple alone	6.06	6.12	6.09	5.83	5.84	5.84	4.25	4.29	4.27	3.60	3.62	3.61
S.Em ±	**0.31**	**0.31**	**0.31**	**0.32**	**0.30**	**0.31**	**0.29**	**0.24**	**0.26**	**0.19**	**0.19**	**0.19**
CD @ 5 %	**0.89**	**0.90**	**0.89**	**0.93**	**0.88**	**0.90**	**0.85**	**0.69**	**0.75**	**NS**	**NS**	**NS**

Note: CA–Custard apple
NS– Non significant



T_1: CA + Finger millet
T_2: CA + Fodder maize
T_3: CA + Field bean
T_4: CA + Niger
T_5: CA + Chilli
T_6: CA + Cowpea
T_7: CA + Foxtail millet
T_8: Finger millet alone
T_9: Fodder maize alone
T_{10}: Field bean alone
T_{11}: Niger alone
T_{12}: Chilli alone
T_{13}: Cowpea alone
T_{14}: Foxtail millet alone
T_{15}: Custard apple alone

Fig. 4.6: Total carbon content (g kg^{-1}) in soil at different depths as influenced by custard apple based agri-horticulture system after harvest of crops

At 0–15 cm soil depth, significantly higher total carbon in soil was noticed during 2017 and 2018 in treatment CA + Cowpea (7.19 and 7.19 g kg^{-1}, respectively) (T_6) followed by CA + Field bean (7.11 and 7.13 g kg^{-1}, respectively) (T_3), cowpea alone (6.95 and 6.95 g kg^{-1}, respectively) (T_{13}) and field bean alone (6.85 and 6.85 g kg^{-1}, respectively) (T_{10}). The treatments CA + Finger millet (6.50 and 6.55 g kg^{-1}, respectively) (T_1), CA + Niger (6.23 and 6.27 g kg^{-1}, respectively) (T_4) and CA+ Chilli (6.28 and 6.33 g kg^{-1}, respectively) (T_5) were found to be on par with each other during 2017 and 2018, respectively. The treatments Niger alone (5.86 and 5.88 g kg^{-1}) (T_{11}), Chilli alone (6.13 and 6.17 g kg^{-1}) (T_{12}) and Foxtail millet alone (5.94 and 5.95 g kg^{-1}) (T_{14}) were found on par with each other during 2017 and 2018, respectively. The treatment fodder maize alone (5.77 and 5.80 g kg^{-1}, respectively) (T_9) recorded significantly lower total carbon content of soil during 2017 and 2018 followed by CA + Fodder maize (5.99 and 5.99 g kg^{-1}, respectively) (T_2).

At 15–30 cm depth, significantly higher total carbon content was noticed in treatment CA + Cowpea (7.06 and 7.09 g kg^{-1}) (T_6) recorded followed by CA + Field bean (6.99 and 6.98 g kg^{-1}) (T_3) during 2017 and 2018, respectively. During 2017 and 2018, significantly lower total carbon values were recorded in fodder maize alone (5.76 and 5.80 g kg^{-1}, respectively) (T_9) followed by CA + Fodder maize (6.01 and 6.05 g kg^{-1}, respectively) (T_2) and custard apple alone (5.83 and 5.84 g kg^{-1}, respectively) (T_{15}). At 30–60 depth, significantly higher total carbon content during 2017 and 2018 was maintained under CA + Cowpea (T_6) (5.40 and 5.40 g kg^{-1}, respectively) followed by CA + Field bean (T_3) (5.39 and 5.44 g kg^{-1}, respectively), Cowpea alone (T_{13}) (5.22 and 5.26 g kg^{-1}, respectively) and Field bean alone (T_{10}) (5.15 and 5.17 g kg^{-1}, respectively). Significantly lower values were recorded with Fodder maize alone (T_9) (4.14 and 4.13 g kg^{-1}, respectively) and CA + Fodder maize (T_2) (4.29 and 4.32 g kg^{-1}, respectively) treatments during 2017 and 2018. At 60–90 cm depth of soil the total carbon content was found non–significant among the treatments but higher values were maintained under custard apple + legume intercropping systems and lower values under fodder maize treatments.

Pooled analysis of two years (2017 and 2018) experimental data revealed that there was a significant difference among the treatments with respect to the total carbon content of soil. At 0–15 cm depth of soil the treatment CA + Cowpea (7.19 g kg^{-1}) (T_6) maintained significantly higher total carbon content followed by CA + Field bean (7.12 g kg^{-1}) (T_3), Cowpea alone (6.94 g kg^{-1}) (T_{13}) and Field bean alone (6.85 g kg^{-1}) (T_{10}). The treatments with legume crops recorded higher total carbon in soil might be due to higher carbon input from both legumes as well as custard apple. Although legume crops produce less biomass and return less total C to the soil, these crop residues can be converted more efficiently into SOC than other crops. Similar findings were reported by Comeau (2012) who reported that the low amount of pulse crop residue with low C:N ratio can produce more SOC than a higher amount of crop residue having a high C:N ratio. The treatments CA + Finger millet (6.52 g kg^{-1}) (T_1), CA + Niger (6.25 g kg^{-1}) (T_4), CA + Chilli (6.31 g kg^{-1}) (T_5), CA + Foxtail millet (6.07 g kg^{-1}) (T_7), Finger millet alone (6.34 g kg^{-1}) (T_8), Niger alone (5.87 g kg^{-1}) (T_{11}), Chilli alone (6.15 g kg^{-1}) (T_{12}), Foxtail millet alone (5.95 g kg^{-1}) (T_{14}) and Custard apple alone (6.09 g kg^{-1}) (T_{15}) were found to be on par with each other. Significantly lower total carbon content was recorded in treatment T_9 (Fodder maize alone) (5.79 g kg^{-1}) followed by T_2 (CA + Fodder maize) (5.99 g kg^{-1}) at 0–15 cm depth of soil. Lower total carbon in fodder maize treatment compared to others might be due to lower carbon input from fodder maize since, it was removed from field for fodder purpose. The increase in total carbon content under custard apple based intercropping systems might be due to the increased quantity of plant residues addition through litterfall and higher root biomass from both trees and agriculture crops thereby reducing soil C loss through oxidation which is more pronounced in sole crops. Similar results also reported by Liao and Boutton (2008).

Pooled data revealed that at 15–30 and 30–60 cm depth of soil, significantly higher total carbon content was recorded in treatment T_6 (CA + Cowpea) (7.08 and 5.40 g kg^{-1}, respectively) followed by T_3 (CA + Field bean) (6.99 and 5.41 g kg^{-1}, respectively). Significantly lower total carbon was maintained under treatment T_9 (Fodder maize alone) (5.78 and 4.14 g kg^{-1}) followed by T_2 (CA + Fodder maize) (6.03 and 4.31 g kg^{-1}) at 15–30, and 30–60 cm depth of soil, respectively. At 60–90 cm depth of soil the total carbon content was found non–significant among the treatments but higher values were

maintained under custard apple+legume intercropping systems and lower values under fodder maize. Irrespective of treatments, total carbon content was decreased with increase in soil depth. The decrease in total carbon status with depth might be due to most of the litter fall and organic matter addition occurs on the surface and very little is incorporated in deeper layers except for addition of C through the decomposing plant roots.

4.5 Effect of custard apple based agri–horticulture system on nitrogen dynamics in soil

4.5.1 Effect of custard apple based agri–horticulture system on available nitrogen content of soil at different depths

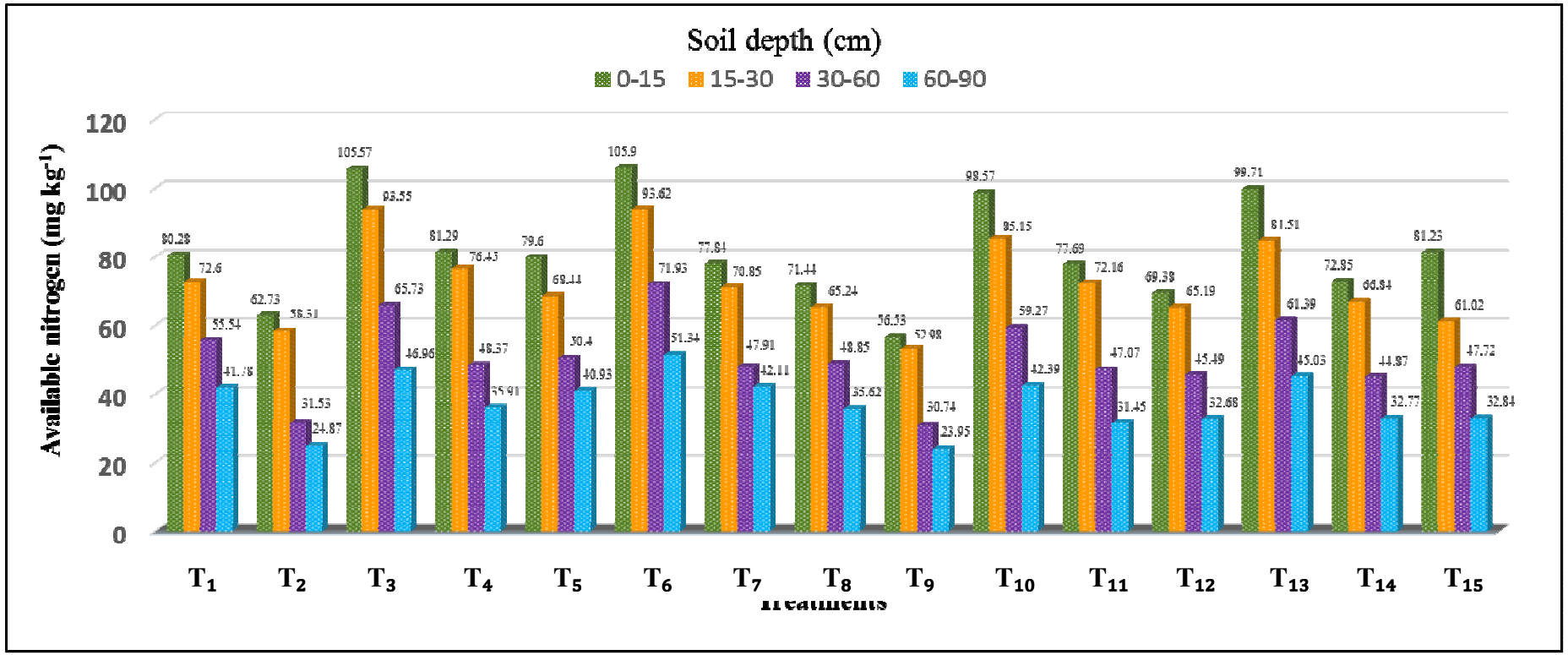
Available N varied significantly at all depths under custard apple based agri–horticulture system and the data is presented in Table 4.15 and Figure 4.7. The treatments with legume crops recorded significantly higher available N at all depths. At 0–15 cm depth, the available N was found significantly higher under CA + Cowpea (T_6) (105.31 and 106.48 mg kg^{-1}) treatment during 2017 and 2018, respectively. This was followed by CA + Field bean (T_3) (104.70 and 106.43 mg kg^{-1}), Cowpea alone (T_{13}) (98.87 and 100.55 mg kg^{-1}) and Field bean alone (T_{10}) (98.30 and 98.83 mg kg^{-1}) treatments during 2017 and 2018, respectively. The treatments CA + Niger (T_4) (80.79 and 81.78 mg kg^{-1}), CA + Chilli (T_5) (80.28 and 78.91 mg kg^{-1}), CA + Finger millet (T_1) (79.57 and 80.99 mg kg^{-1}) and CA + Foxtail millet (T_7) (77.44 and 78.23 mg kg^{-1}) were found on par with each other during 2017 and 2018, respectively. Significantly lower available N content was recorded under Fodder maize alone (T_9) (54.12 and 58.96 mg kg^{-1}) and CA + Fodder maize (T_2) (62.12 and 63.33 mg kg^{-1}) during 2017 and 2018, respectively. Similar trend was maintained at other depths of soil also with higher available nitrogen under treatments with legume crops.

During 2017 and 2018, significantly higher available N was maintained under CA + Cowpea (T_6) (91.33 and 95.90, 70.17 and 73.68, 50.09 and 52.59 mg kg^{-1}) at 15–30, 30–60 and 60–90 cm depth, respectively. This was followed by CA + Field bean (T_3) (90.92 and 96.19, 65.21 and 66.25, 47.67 and 46.24 mg kg^{-1}) at 15–30, 30–60 and 60–90 cm depth, respectively.

Table 4.15: Available nitrogen content (mg kg^{-1}) in soil at different depths as influenced by custard apple based agri–horticulture system after harvest of crops during 2017 and 2018

Treatments	Soil depth (cm)											
	0-15			15-30			30-60			60-90		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1: CA + Finger millet	79.57	80.99	80.28	70.49	74.72	72.60	53.92	57.16	55.54	40.56	42.99	41.78
T_2: CA + Fodder maize	62.12	63.33	62.73	56.05	60.57	58.31	32.85	30.22	31.53	25.90	23.83	24.87
T_3: CA + Field bean	104.70	106.43	105.57	90.92	96.19	93.55	65.21	66.25	65.73	47.67	46.24	46.96
T_4: CA + Niger	80.80	81.78	81.29	75.97	76.93	76.45	49.35	47.38	48.37	36.65	35.18	35.91
T_5: CA + Chilli	80.28	78.91	79.60	67.28	69.59	68.44	51.43	49.37	50.40	40.74	41.11	40.93
T_6: CA + Cowpea	105.31	106.48	105.90	91.33	95.90	93.62	70.17	73.68	71.93	50.09	52.59	51.34
T_7: CA + Foxtail millet	77.44	78.23	77.84	71.06	70.64	70.85	48.40	47.43	47.91	42.53	41.68	42.11
T_8: Finger millet alone	71.78	71.10	71.44	63.79	66.69	65.24	47.76	49.94	48.85	36.58	34.65	35.62
T_9: Fodder maize alone	54.10	58.96	56.53	51.94	54.02	52.98	30.13	31.34	30.74	23.48	24.42	23.95
T_{10}: Field bean alone	98.30	98.83	98.57	82.63	87.67	85.15	59.04	59.50	59.27	43.70	41.08	42.39
T_{11}: Niger alone	77.14	78.24	77.69	69.72	74.60	72.16	45.48	48.66	47.07	30.38	32.51	31.45
T_{12}: Chilli alone	68.79	69.97	69.38	63.02	67.35	65.19	46.07	44.92	45.49	34.22	31.14	32.68
T_{13}: Cowpea alone	98.87	100.55	99.71	85.79	83.22	84.51	60.80	61.98	61.39	44.19	45.86	45.03
T_{14}: Foxtail millet alone	73.19	72.51	72.85	67.18	66.49	66.84	44.25	45.48	44.87	33.44	32.10	32.77
T_{15}: Custard apple alone	82.72	79.75	81.23	59.82	62.21	61.02	46.78	48.65	47.72	32.19	33.48	32.84
S.Em ±	**3.68**	**4.72**	**4.12**	**3.40**	**3.98**	**3.62**	**2.83**	**2.94**	**2.74**	**1.81**	**1.97**	**1.88**
CD @ 5 %	**10.67**	**13.68**	**11.92**	**9.84**	**11.53**	**10.49**	**8.19**	**8.52**	**7.94**	**5.24**	**5.71**	**5.44**

Note: CA–Custard apple



T_1: CA + Finger millet
T_2: CA + Fodder maize
T_3: CA + Field bean
T_4: CA + Niger
T_5: CA + Chilli
T_6: CA + Cowpea
T_7: CA + Foxtail millet
T_8: Finger millet alone
T_9: Fodder maize alone
T_{10}: Field bean alone
T_{11}: Niger alone
T_{12}: Chilli alone
T_{13}: Cowpea alone
T_{14}: Foxtail millet alone
T_{15}: Custard apple alone

Fig. 4.7: Available nitrogen content (mg kg^{-1}) in soil at different depths as influenced by custard apple based agri-horticulture system after harvest of crops

At 15–30, 30–60 and 60–90 cm depth, significantly lower available N was recorded under Fodder maize alone (51.94 and 54.02, 30.13 and 31.34, 23.48 and 24.42 mg kg^{-1}, respectively).

Pooled analysis of 2017 and 2018 experimental data revealed that available N content varied significantly among the treatments. Significantly higher available N was recorded in treatment CA + Cowpea (T_6) (105.90 mg kg^{-1}) followed by CA + Field bean (T_3) (105.57 mg kg^{-1}), Cowpea alone (T_{13}) (99.71 mg kg^{-1}) and Field bean alone (T_{10}) (98.57 mg kg^{-1}) at 0–15 cm depth of soil. Higher available N in treatments with legume crops compared to others might be attributed to their capacity to fix atmospheric N and its subsequent addition to soil after harvest of the crop. It also could be attributed to legume crops, such as cowpea and field bean, which supplied greater amount of N due to their higher N concentration and more rapid decomposition as well as incorporation of residue to a greater depth in the soil. Legumes, because of higher N concentration and lower C/N ratio, decompose rapidly in the soil and supply greater amount of N than non–legumes (Sainju *et al.,* 2002). Nitrogen mineralization can be increased with inclusion of legume crops in the rotation (Carpenter Boggs *et al.,* 2000). The treatment T_9 (Fodder maize alone) (56.53 mg kg^{-1}) recorded significantly lower available N compared to other treatments and this was followed by T_2 (CA + Fodder maize) (62.73 mg kg^{-1}). Lower available N in fodder maize might be due to decreased organic carbon content, higher removal of nitrogen in crop dry matter and non -addition of crop residue to soil. However, available N was non–significant among treatments T_1 (CA + Finger millet) (80.28 mg kg^{-1}), T_4 (CA + Niger) (81.29 mg kg^{-1}), T_5 (CA + Chilli) (79.60 mg kg^{-1}), T_7 (CA + Foxtail millet) (77.84 mg kg^{-1}) and T_{15} (Custard apple alone) (81.23 mg kg^{-1}). The treatments T_8 (Finger millet alone) (71.44 mg kg^{-1}), T_{11} (Niger alone) (77.69 mg kg^{-1}) and T_{14} (Foxtail millet alone) (72.85 mg kg^{-1}) were found on par with each other. Similar trend was maintained at all depths of soil with higher values in treatments with legume crops. The higher content of available N on surface layers under intercropping systems is attributed to accumulation and decomposition of litter fall and greater biomass added to soil. It leads to mineralization of organic N from the litter and its release into the soil and improved available N (Baljit Singh and Sharma, 2012).

Pooled data suggested that the available N varied significantly among the treatments at 15–30, 30–60 and 60–90 cm depth of soil. At 15–30, 30–60 and 60–90 cm depth, significantly higher available N was maintained in treatment CA + Cowpea (T_6) (93.62, 71.93 and 51.34 mg kg^{-1}, respectively) followed by T_3 (CA + Field bean) (93.55, 65.73 and 46.96 mg kg^{-1}, respectively). Fodder maize alone (T_9) (52.98, 30.74 and 23.95 mg kg^{-1}) recorded significantly lower available N in soil at 15–30, 30–60 and 60–90 cm depth, respectively. The available N found to be maximum in surface horizons and decreased regularly with depth which is due to decreasing trend of organic carbon with depth and cultivation of crops are mainly confined to the surface horizon (Rhizosphere) only and at regular interval the depleted nitrogen content is supplemented by the external addition of fertilizers during crop cultivation (Khanday *et al.,* 2018). Irrespective of the treatments, available N content in soil was decreased with increase in depth. This might be due to decreased organic matter content of the soil at lower depths since nitrogen is directly related to the organic matter content. Significant amount of available N at lower depths might be attributed to leaching of soluble organic nitrogen as well as inorganic (nitrate) nitrogen from top layers and its accumulation in deeper depths of soil (Saha *et al.,* 2000). Saswati Ghosh *et al.* (2017) reported that under guava + banana intercropping system the available nitrogen content of soil increased in surface soil and decreased with depth.

4.5.2 Effect of custard apple based agri–horticulture system on ammonical nitrogen content of soil at different depths

Custard apple based agri–horticulture system significantly influenced the ammonical nitrogen content and its distribution in soil profile. At all depths ammonical nitrogen varied significantly and the data are presented in Table 4.16 and Figure 4.8.

At 0–15 cm depth, significantly higher ammonical nitrogen was found in treatment CA + Cowpea (T_6) (39.79 and 43.78 mg kg^{-1}) followed by T_3 (CA + Field bean) (37.51 and 42.38 mg kg^{-1}) during 2017 and 2018, respectively. However, this was on par with T_{13} (Cowpea alone) (35.79 and 40.72 mg kg^{-1}) and T_{10} (Field bean alone) (34.70 and 39.62 mg kg^{-1}) during 2017 and 2018, respectively.

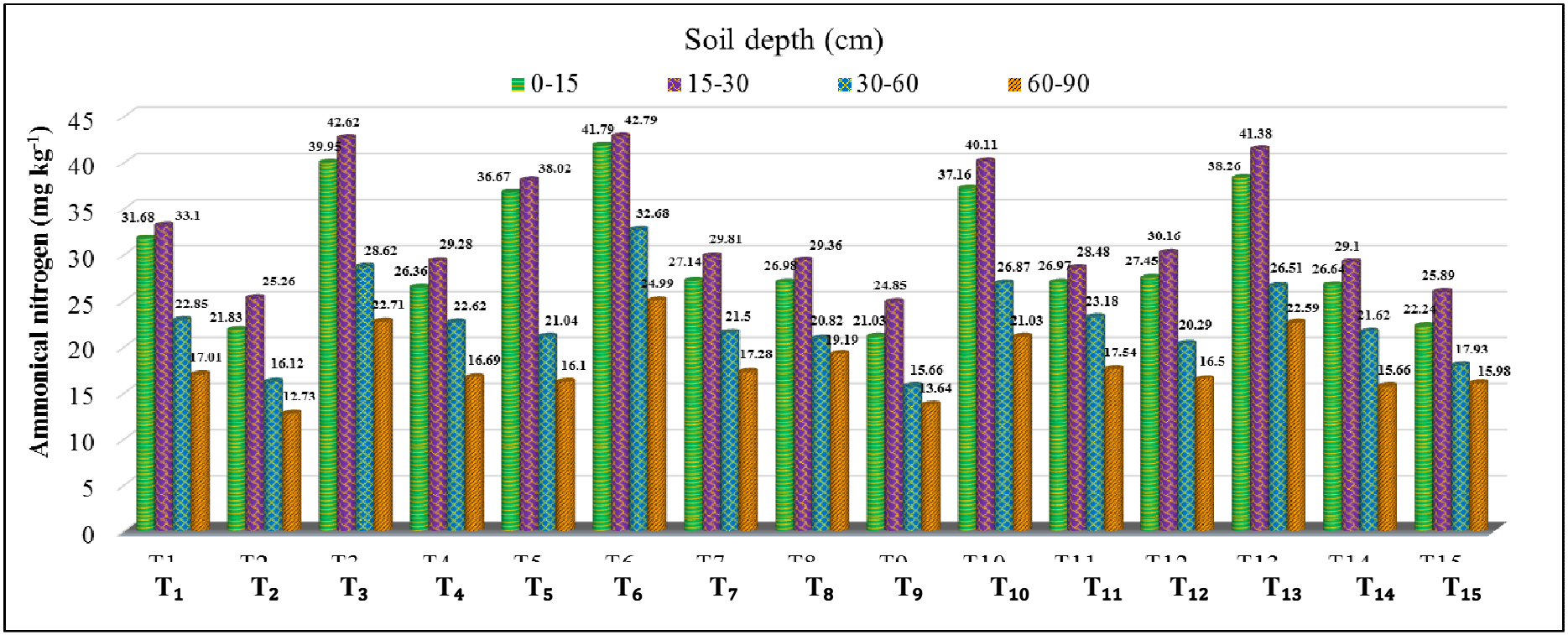
Table 4.16: Ammonical nitrogen content (mg kg^{-1}) in soil at different depths as influenced by custard apple based agri–horticulture system after harvest of crops during 2017 and 2018

Treatments	Soil depth (cm)											
	0-15			15-30			30-60			60-90		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1: CA + Finger millet	29.78	33.57	31.68	30.68	35.52	33.10	22.19	23.52	22.85	16.48	17.53	17.01
T_2: CA + Fodder maize	21.17	22.48	21.83	24.23	26.29	25.26	16.27	15.97	16.12	13.26	12.20	12.73
T_3: CA + Field bean	37.51	42.38	39.95	39.71	45.52	42.62	27.53	29.70	28.62	22.55	22.87	22.71
T_4: CA + Niger	25.36	27.35	26.36	28.85	29.70	29.28	23.08	22.16	22.62	17.03	16.35	16.69
T_5: CA + Chilli	36.40	36.94	36.67	37.13	38.92	38.02	21.47	20.61	21.04	16.43	15.77	16.10
T_6: CA + Cowpea	39.79	43.78	41.79	40.28	45.29	42.79	30.59	34.77	32.68	24.38	25.60	24.99
T_7: CA + Foxtail millet	27.41	26.86	27.14	30.11	29.51	29.81	21.71	21.28	21.50	17.45	17.10	17.28
T_8: Finger millet alone	26.54	27.42	26.98	29.54	29.18	29.36	21.68	19.95	20.82	18.59	19.79	19.19
T_9: Fodder maize alone	19.63	22.42	21.03	24.36	25.33	24.85	15.35	15.96	15.66	13.37	13.90	13.64
T_{10}: Field bean alone	34.70	39.62	37.16	37.74	42.48	40.11	26.67	27.07	26.87	21.16	20.89	21.03
T_{11}: Niger alone	25.57	28.36	26.97	27.51	29.44	28.48	22.39	23.96	23.18	16.94	18.13	17.54
T_{12}: Chilli alone	25.08	29.82	27.45	28.96	31.35	30.16	21.24	19.33	20.29	17.28	15.72	16.50
T_{13}: Cowpea alone	35.79	40.72	38.26	38.45	44.30	41.38	26.92	26.11	26.51	22.94	22.25	22.59
T_{14}: Foxtail millet alone	25.66	27.63	26.64	28.16	30.03	29.10	22.06	21.18	21.62	15.98	15.34	15.66
T_{15}: Custard apple alone	20.82	23.65	22.24	25.38	26.40	25.89	17.09	18.77	17.93	15.66	16.29	15.98
S.Em ±	**1.50**	**1.54**	**1.51**	**1.43**	**1.80**	**1.57**	**1.04**	**1.22**	**1.12**	**1.02**	**0.87**	**0.90**
CD @ 5 %	**4.34**	**4.45**	**4.37**	**4.13**	**5.21**	**4.54**	**3.02**	**3.53**	**3.25**	**2.94**	**2.53**	**2.61**

Note: CA–Custard apple

Fodder maize alone (T_9) (19.63 and 22.42 mg kg^{-1}) recorded significantly lower ammonical nitrogen content at 0–15 cm depth followed by T_2 (CA + Fodder maize) (21.17 and 22.48 mg kg^{-1}) during 2017 and 2018, respectively. At 15–30, 30–60 and 60–90 cm depth, significantly higher ammonical nitrogen was maintained under CA + Cowpea (T_6) (40.28 and 45.29, 30.59 and 34.77, 24.38 and 25.60 mg kg^{-1}, respectively) treatment followed by T_3 (CA + Field bean) (39.71 and 45.52, 27.53 and 29.70, 22.55 and 22.87 mg kg^{-1}, respectively) during 2017 and 2018. Significantly lower values were observed in treatment Fodder maize alone (T_9) (24.36 and 25.33, 15.35 and 15.96, 13.37 and 13.90 mg kg^{-1}, respectively) during 2017 and 2018 at 15–30, 30–60 and 60–90 cm depth of soil.

Pooled analysis revealed that there was significant variation in ammonical nitrogen content of soil at various depths. At 0–15 cm depth, significantly higher ammonical nitrogen was found in treatment CA + Cowpea (T_6) (41.79 mg kg^{-1}). However, this was on par with CA + Field bean (T_3) (39.95 mg kg^{-1}), Cowpea alone (T_{13}) (38.26 mg kg^{-1}) and Field bean alone (T_{10}) (37.16 mg kg^{-1}). Significant amount of ammonical nitrogen in legume treatments is due increased crop residue addition and its subsequent mineralization in soil. Higher release of NH_4–N from leguminous plant leaves has been reported by Hussain *et al.* (1990). This could also be attributed to the contribution made by decomposing litter fall, decaying dead roots and secreted metabolites and exudates (Sharma *et al.,* 2009). The treatments T_4 (CA + Niger) (26.36 mg kg^{-1}), T_7 (CA + Foxtail millet) (27.14 mg kg^{-1}), T_{11} (Niger alone) (26.97 mg kg^{-1}), T_{12} (Chilli alone) (27.45 mg kg^{-1}) and T_{14} (Foxtail millet alone) (26.64 mg kg^{-1}) were found to be on par with each other. Fodder maize alone (T_9) (21.03 mg kg^{-1}) recorded significantly lower ammonical nitrogen content followed by T_2 (CA + Fodder maize) (21.83 mg kg^{-1}) and T_{15} (Custard apple alone) (23.65 mg kg^{-1}). Lower ammonical nitrogen in fodder maize might be due to lower organic matter content in soil, higher nitrogen uptake by crop as well as non -addition of crop residues. The treatment wise trend in subsurface layer was almost similar with that of surface layer. However, subsurface layers recorded marginally lower values as compared to surface layer in all the treatments. Irrespective of treatments, the ammonical nitrogen content of soils



T_1: CA + Finger millet
T_2: CA + Fodder maize
T_3: CA + Field bean
T_4: CA + Niger
T_5: CA + Chilli
T_6: CA + Cowpea
T_7: CA + Foxtail millet
T_8: Finger millet alone
T_9: Fodder maize alone
T_{10}: Field bean alone
T_{11}: Niger alone
T_{12}: Chilli alone
T_{13}: Cowpea alone
T_{14}: Foxtail millet alone
T_{15}: Custard apple alone

Fig. 4.8: Ammonical nitrogen content (mg kg^{-1}) in soil at different depths as influenced by custard apple based agri-horticulture system after harvest of crops

decreased with increase in depth of soil. Purnananda *et al.* (2017) showed that ammonical nitrogen content soils under coconut land use system decreased with depth due to lower rate of mineralization in the subsurface soils owing to less organic matter. Similar depth wise distribution of NH_4–N has also been reported by Bhardwaj *et al*. (1994).

Pooled analysis suggested that the ammonical nitrogen content varied significantly at lower depths of soil. At 15–30, 30–60 and 60–90 cm depth of soil, the treatment CA + Cowpea (T_6) maintained significantly higher (42.79, 32.68 and 24.99 mg kg^{-1}, respectively) ammonical nitrogen. Significantly lower ammonical nitrogen content at 15–30, 30–60 and 60–90 cm depth was recorded in Fodder maize alone (T_9) (24.85, 15.66 and 13.64 mg kg^{-1}, respectively). Significant amount ammonical N at lower depths might be attributed to leaching of soluble organic nitrogen from top layers and its mineralization in deeper depths of soil. Similar findings are reported by Saha *et al.* (2000).

4.5.3 Effect of custard apple based agri–horticulture system on nitrate nitrogen content of soil at different depths

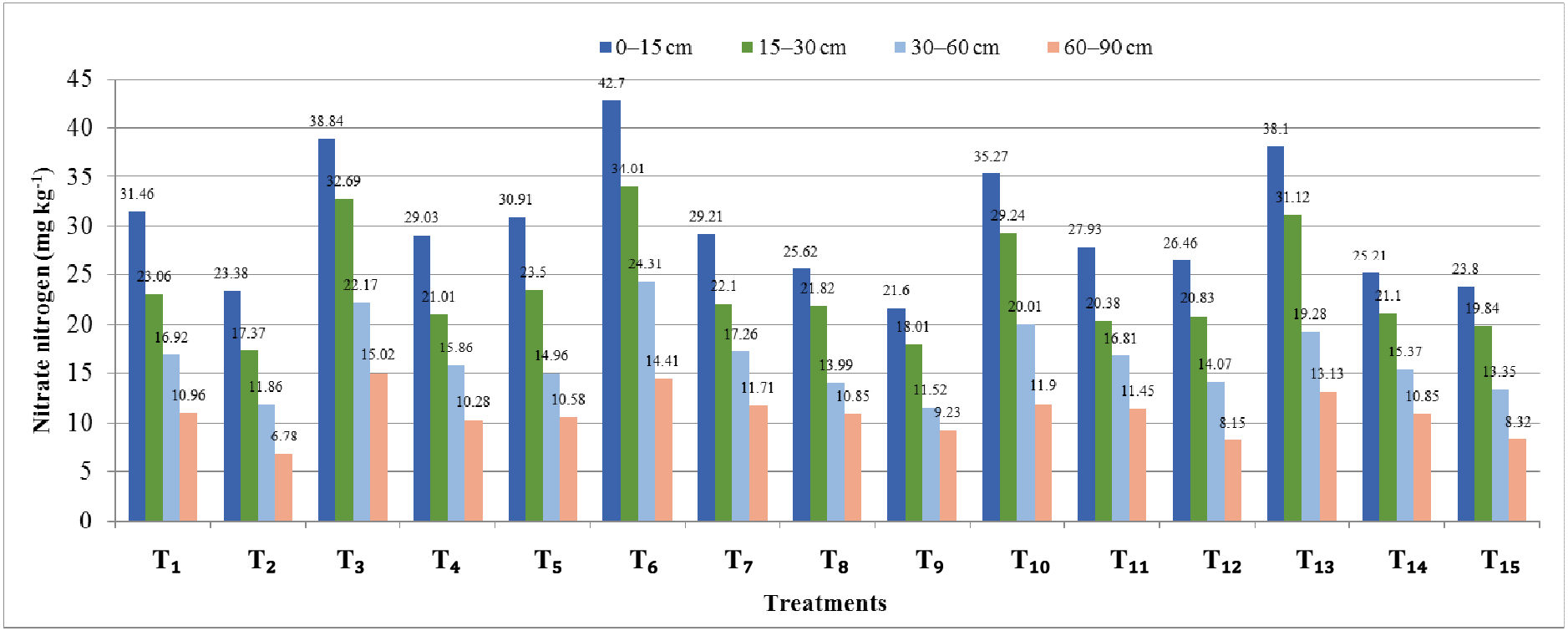
The nitrate nitrogen content was significantly varied among the treatments due to custard apple based agri–horticulture system in surface as well as subsurface soil samples. The data pertaining to nitrate nitrogen content at various depths is presented in Table 4.17 and Figure 4.9.

At 0–15 cm depth, significantly higher nitrate nitrogen was recorded in treatment CA + Cowpea (T_6) (42.63 and 42.76 mg kg^{-1}) followed by T_3 (CA + Field bean) (39.43 and 38.25 mg kg^{-1}), T_{13} (Cowpea alone) (38.68 and 37.52 mg kg^{-1}) and T_{10} (Field bean) (36.36 and 34.18 mg kg^{-1}) during 2017 and 2018, respectively. Fodder maize alone (T_9) (21.17 and 22.02 mg kg^{-1}) recorded significantly lower nitrate nitrogen content at 0–15 cm depth during 2017 and 2018, respectively. However, this was on par with T_{15} (Custard apple alone) (22.35 and 25.24 mg kg^{-1}, respectively) and T_2 (CA + Fodder maize) (24.35 and 22.40 mg kg^{-1}, respectively). Similar trend was maintained at all other depths also. At 15–30, 30–60 and 60–90 cm depth, significantly higher nitrate nitrogen was maintained under treatment CA + Cowpea (T_6) (32.67 and 35.35, 23.71 and 24.90, 14.06 and 14.76

Table 4.17: Nitrate nitrogen content (mg kg^{-1}) in soil at different depths as influenced by custard apple based agri–horticulture system after harvest of crops during 2017 and 2018

Treatments	Soil depth (cm)											
	0-15			15-30			30-60			60-90		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1: CA + Finger millet	30.54	32.37	31.46	22.39	23.73	23.06	16.42	17.41	16.92	10.64	11.28	10.96
T_2: CA + Fodder maize	24.35	22.40	23.38	18.09	16.64	17.37	12.35	11.36	11.86	7.06	6.50	6.78
T_3: CA + Field bean	39.43	38.25	38.84	31.65	33.72	32.69	22.51	21.83	22.17	14.23	15.80	15.02
T_4: CA + Niger	30.65	27.42	29.03	21.44	20.58	21.01	16.18	15.53	15.86	9.47	11.09	10.28
T_5: CA + Chilli	34.09	27.73	30.91	22.96	24.04	23.50	15.27	14.66	14.96	10.28	10.87	10.58
T_6: CA + Cowpea	42.63	42.76	42.70	32.67	35.35	34.01	23.71	24.90	24.31	14.06	14.76	14.41
T_7: CA + Foxtail millet	29.51	28.92	29.21	22.32	21.87	22.10	17.43	17.08	17.26	11.32	12.09	11.71
T_8: Finger millet alone	26.68	24.55	25.62	22.17	21.46	21.82	14.05	13.93	13.99	10.78	10.92	10.85
T_9: Fodder maize alone	21.17	22.02	21.60	17.65	18.36	18.01	11.29	11.74	11.52	8.56	9.90	9.23
T_{10}: Field bean alone	36.36	34.18	35.27	30.14	28.33	29.24	19.08	20.94	20.01	12.27	11.53	11.90
T_{11}: Niger alone	27.95	27.91	27.93	19.69	21.07	20.38	16.24	17.38	16.81	10.09	12.80	11.45
T_{12}: Chilli alone	27.19	25.74	26.46	20.24	21.42	20.83	14.21	13.93	14.07	8.53	7.76	8.15
T_{13}: Cowpea alone	38.68	37.52	38.10	30.58	31.66	31.12	19.57	18.98	19.28	13.84	12.42	13.13
T_{14}: Foxtail millet alone	25.72	24.69	25.21	21.69	20.51	21.10	14.66	16.07	15.37	10.05	11.65	10.85
T_{15}: Custard apple alone	22.35	25.24	23.80	19.42	20.25	19.84	13.09	13.61	13.35	8.15	8.48	8.32
S.Em ±	**1.46**	**1.42**	**1.44**	**1.53**	**1.29**	**1.36**	**0.79**	**0.83**	**0.81**	**0.57**	**0.55**	**0.55**
CD @ 5 %	**4.24**	**4.11**	**4.17**	**4.43**	**3.73**	**3.94**	**2.28**	**2.41**	**2.33**	**1.65**	**1.58**	**1.61**

Note: CA–Custard apple



T_1: CA + Finger millet
T_2: CA + Fodder maize
T_3: CA + Field bean
T_4: CA + Niger
T_5: CA + Chilli
T_6: CA + Cowpea
T_7: CA + Foxtail millet
T_8: Finger millet alone
T_9: Fodder maize alone
T_{10}: Field bean alone
T_{11}: Niger alone
T_{12}: Chilli alone
T_{13}: Cowpea alone
T_{14}: Foxtail millet alone
T_{15}: Custard apple alone

Fig. 4.9: Nitrate nitrogen content (mg kg^{-1}) in soil at different depths as influenced by custard apple based agri–horticulture system after harvest of crops

mg kg^{-1}, respectively) followed by T_3 (CA + Field bean) (31.65 and 33.72, 22.51 and 21.83, 14.23 and 15.80 mg kg^{-1}, respectively) during 2017 and 2018. Significantly lower nitrate nitrogen was found in treatment T_9 (Fodder maize alone) (17.65 and 18.36, 11.29 and 11.74, 8.56 and 9.90 mg kg^{-1}) during 2017 and 2018 at 15–30, 30–60 and 60–90 cm depth, respectively.

Pooled analysis of the two years experimental data revealed that higher nitrate nitrogen content was found at surface soil compared to deeper layers. The topsoil is a better aerobic environment with higher oxidation reduction potential. The denitrification is restrained while the nitrification get strengthened leading to accumulation of nitrate nitrogen (Robert and Hassan, 2003). Significantly higher nitrate nitrogen was found in treatment CA + Cowpea (T_6) (42.70 mg kg^{-1}) at 0–15 cm depth. However, this was followed by treatments T_3 (CA + Field bean) (38.84 mg kg^{-1}), T_{13} (Cowpea alone) (38.10 mg kg^{-1}) and T_{10} (Field bean) (35.27 mg kg^{-1}). Significant amount of nitrate nitrogen in legume treatments might be due to release of nitrogen fixed in nodules after harvest which upon mineralization increased the nitrate nitrogen content of soil. This may also be due to nitrification process wherein the ammonical nitrogen converted to nitrate nitrogen by microbes (Fabian Beeckman *et al.,* 2018). Whereas, there was no significant difference between the treatments T_1 (CA + Finger millet) (31.46 mg kg^{-1}), T_4 (CA + Niger) (27.42 mg kg^{-1}), T_5 (CA + Chilli) (27.73 mg kg^{-1}) and T_7 (CA + Foxtail millet) (28.92 mg kg^{-1}). The treatment T_9 (Fodder maize alone) (21.60 mg kg^{-1}) recorded significantly lower nitrate nitrogen content followed by T_2 (CA + Fodder maize) (23.38 mg kg^{-1}) and T_{15} (Custard apple alone) (23.80 mg kg^{-1}). Similar trend was maintained at all depths of soil with higher values in treatments with legume crops. The absorption and translation of the plants also influence the vertical distribution of the nitrogen in the soil and the nitrate nitrogen is the main nitrogen form absorbed by the plants. Increase in NO_3–N content in surface soil may be ascribed to nitrification of NH_4–N to NO_3–N by soil microorganisms (Santhy *et al*., 1998). It was also observed that with respective crops higher NO_3–N was recorded under custard apple based intercropping systems than sole crops. This might be due to more organic matter under intercropping systems, which upon decomposition and mineralization might have released more of NO_3–N as

compared to sole crops. This was in accordance with Maia *et al.* (2008) reported higher total nitrogen and NO_3–N in soil under agroforestry system was due to more organic matter accumulation than conventional systems. Nitrate nitrogen content was found maximum at the surface soil than the subsurface due to rapid mineralization of organic matter in surface layer compared to subsurface soils (Purnananda *et al.,* 2017). So, the nitrate content was found decreased with increase in depth of soil.

Pooled analysis suggested that the nitrate nitrogen content varied significantly at lower depths of soil. At 15–30, 30–60 and 60–90 cm depth, the treatment CA + Cowpea (T_6) maintained significantly higher (34.01, 24.31 and 14.41 mg kg^{-1}, respectively) nitrate nitrogen. Significantly lower nitrate nitrogen content at 15–30, 30–60 and 60–90 cm depth was recorded in Fodder maize alone (T_9) (18.01, 11.52 and 9.23 mg kg^{-1}, respectively). Significant amount nitrate N at lower depths might be attributed to leaching of soluble organic nitrogen as well as inorganic (nitrate) nitrogen from top layers and its accumulation in deeper depths of soil (Saha *et al.,* 2000).

4.5.3 Effect of custard apple based agri–horticulture system on total nitrogen content of soil at different depths

Custard apple based agri–horticulture system significantly influenced the total N content at different depths of soil and the data are presented in Table 4.18 and Figure 4.10. Treatments with legume crops recorded significantly higher total N at all depths.

Among different depths irrespective of treatments surface layer (0 to 15 cm) recorded significantly higher total nitrogen content. At 0–15 cm depth, treatment CA + Cowpea (T_6) (636.65 and 638.48 mg kg^{-1}) recorded significantly higher total N followed by CA + Field bean (T_3) (622.48 and 623.81 mg kg^{-1}), Cowpea alone (T_{13}) (611.67 and 613.32 mg kg^{-1}) and Field bean alone (T_{10}) (605.18 and 600.87 mg kg^{-1}) during 2017 and 2018, respectively. Significantly lower total N was recorded under Fodder maize alone (T_9) (457.25 and 465.54 mg kg^{-1}) treatment followed by T_{15} (Custard apple alone) (462.12 and 470.60 mg kg^{-1}) and T_2 (CA + Fodder maize) (480.26 and 481.84 mg kg^{-1}) during 2017 and 2018, respectively.

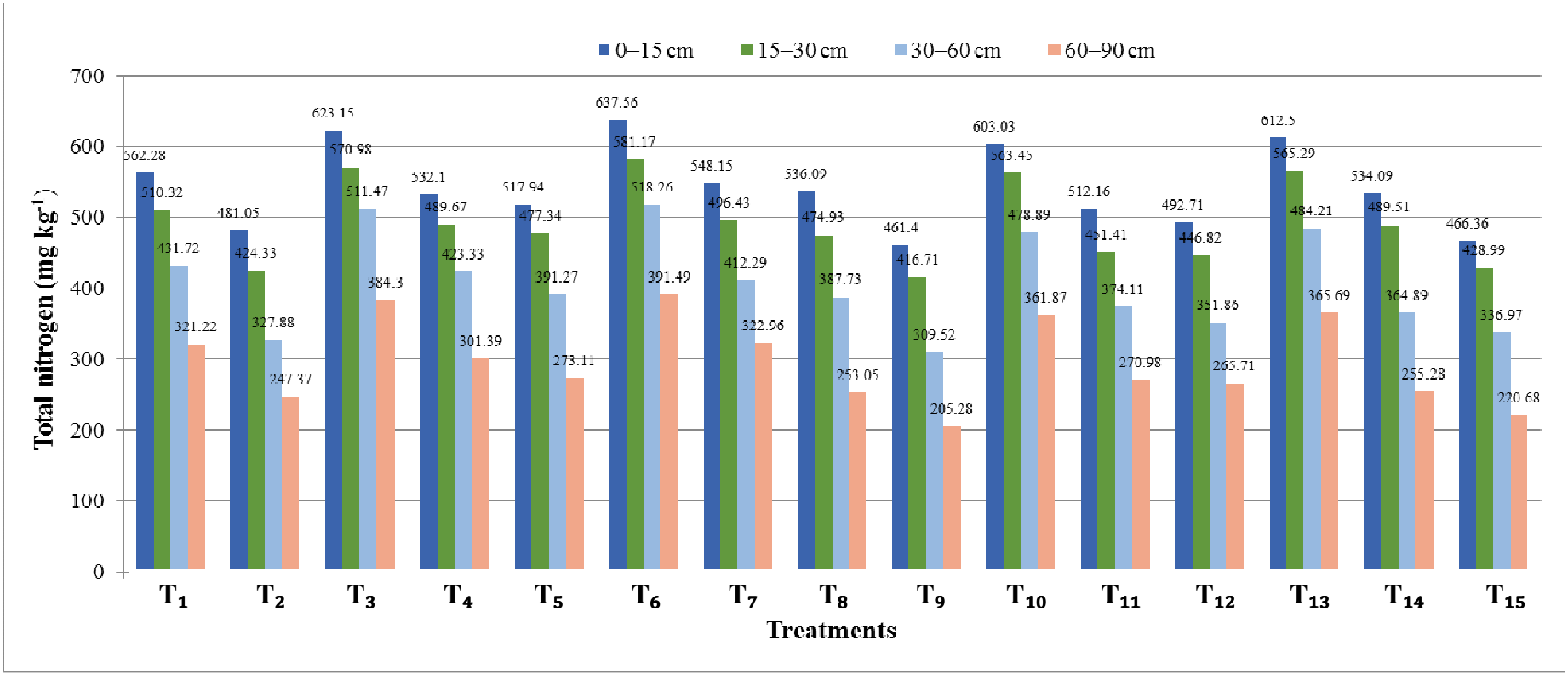
Table 4.18: Total nitrogen content (mg kg^{-1}) in soil at different depths as influenced by custard apple based agri–horticulture system after harvest of crops during 2017 and 2018

Treatments	Soil depth (cm)											
	0-15			15-30			30-60			60-90		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1: CA + Finger millet	560.46	564.09	562.28	508.57	512.08	510.32	432.74	430.70	431.72	320.11	322.32	321.22
T_2: CA + Fodder maize	480.26	481.84	481.05	427.95	420.71	424.33	325.91	329.84	327.88	247.26	247.48	247.37
T_3: CA + Field bean	622.48	623.81	623.15	572.06	569.90	570.98	510.12	512.82	511.47	385.07	383.52	384.30
T_4: CA + Niger	532.75	531.44	532.10	489.46	489.88	489.67	424.31	422.34	423.33	302.44	300.34	301.39
T_5: CA + Chilli	515.76	520.13	517.94	476.87	477.80	477.34	399.25	383.28	391.27	272.56	273.66	273.11
T_6: CA + Cowpea	636.65	638.48	637.56	581.63	580.71	581.17	515.37	521.14	518.26	393.65	389.33	391.49
T_7: CA + Foxtail millet	548.63	547.66	548.15	495.38	497.47	496.43	416.45	408.12	412.29	321.17	324.75	322.96
T_8: Finger millet alone	532.38	539.79	536.09	479.09	470.76	474.93	388.26	387.20	387.73	253.17	252.92	253.05
T_9: Fodder maize alone	457.25	465.54	461.40	418.34	415.07	416.71	303.45	315.59	309.52	206.15	204.40	205.28
T_{10}: Field bean alone	605.18	600.87	603.03	560.25	566.64	563.45	478.23	479.54	478.89	362.75	360.99	361.87
T_{11}: Niger alone	509.33	514.98	512.16	449.19	453.63	451.41	371.12	377.10	374.11	271.48	270.48	270.98
T_{12}: Chilli alone	494.98	490.43	492.71	444.83	448.80	446.82	352.74	350.99	351.86	262.52	268.89	265.71
T_{13}: Cowpea alone	611.67	613.32	612.50	563.74	566.83	565.29	481.43	486.99	484.21	366.18	365.19	365.69
T_{14}: Foxtail millet alone	532.74	535.43	534.09	486.74	492.27	489.51	367.23	362.54	364.89	255.39	255.17	255.28
T_{15}: Custard apple alone	462.12	470.60	466.36	425.48	432.50	428.99	335.26	338.67	336.97	221.25	220.10	220.68
S.Em ±	**27.30**	**26.04**	**26.63**	**26.34**	**23.89**	**25.01**	**19.44**	**20.51**	**19.93**	**14.72**	**14.06**	**14.32**
CD @ 5 %	**79.09**	**75.45**	**77.14**	**76.30**	**69.22**	**72.44**	**56.30**	**59.42**	**57.74**	**42.64**	**40.74**	**41.47**

Note: CA–Custard apple

However the total N was non–significant among T_1 (CA + Finger millet) (560.46 and 564.09 mg kg^{-1}), T_4 (CA + Niger) (532.75 and 531.44 mg kg^{-1}), T_5 (CA + Chilli) (515.76 and 520.13 mg kg^{-1}), T_7 (CA + Foxtail millet) (548.63 and 547.66 mg kg^{-1}), T_8 (Finger millet alone) (532.38 and 539.79 mg kg^{-1}), T_{11} (Niger alone) (509.33 and 514.98 mg kg^{-1}) and T_{14} (Foxtail millet alone) (532.74 and 535.43 mg kg^{-1}) during 2017 and 2018, respectively. CA + Cowpea (T_6) treatment maintained a higher total N at 15–30 (581.63 and 580.71 mg kg^{-1}), 30–60 (515.37 and 521.14 mg kg^{-1}) and 60–90 cm (393.65 and 389.33 mg kg^{-1}) depths of soil and is on par with T_2 (CA + Field bean) during 2017 and 2018, respectively. Significantly lower values were recorded under fodder maize alone (T_9) at 15–30 cm (418.34 and 415.07 mg kg^{-1}), 30–60 cm (303.45 and 315.45 mg kg^{-1}) and 60–90 cm (206.15 and 204.40 mg kg^{-1}) soil depth during 2017 and 2018, respectively.

Pooled analysis of two years experimental data revealed that at 0–15 cm depth significantly higher total N was recorded in treatment CA + Cowpea (T_6) (637.56 mg kg^{-1}). However, this was on par with T_3 (CA + Field bean) (623.15 mg kg^{-1}), T_{13} (Cowpea alone) (612.50 mg kg^{-1}) and T_{10} (Field bean) (603.03 mg kg^{-1}). There was higher accumulation of nitrogen in the treatments with legume crops as compared to other treatments. This could be because of the increased organic carbon content of soil, addition of nitrogen from decomposition of crop residues and litter fall, nitrogen added to soil due to nitrogen fixation in legume crops as well as FYM addition and lesser removal by crop uptake due to lower yields compared other crops resulted in smaller losses of N and build -up of higher concentration of total N. The treatments T_1 (CA + Finger millet) (562.28 mg kg^{-1}), T_4 (CA + Niger) (532.10 mg kg^{-1}), T_5 (CA + Chilli) (517.94 mg kg^{-1}), T_7 (CA + Foxtail millet) (548.15 mg kg^{-1}), T_8 (Finger millet alone) (536.09 mg kg^{-1}), T_{11} (Niger alone) (512.16 mg kg^{-1}) and T_{14} (Foxtail millet alone) (534.09 mg kg^{-1}) were found on par with each other. Significantly lower total N content was found in treatment T_9 (Fodder maize alone) (461.40 mg kg^{-1}) followed by T_{15} (Custard apple alone) (466.36 mg kg^{-1}) and T_2 (CA + Fodder maize) (481.05 mg kg^{-1}). The lower total nitrogen in other treatments compared to treatments with legume crops may be due to over utilization of the nutrients by different components in the other treatments as returned to soil in the



T_1: CA + Finger millet
T_2: CA + Fodder maize
T_3: CA + Field bean
T_4: CA + Niger
T_5: CA + Chilli
T_6: CA + Cowpea
T_7: CA + Foxtail millet
T_8: Finger millet alone
T_9: Fodder maize alone
T_{10}: Field bean alone
T_{11}: Niger alone
T_{12}: Chilli alone
T_{13}: Cowpea alone
T_{14}: Foxtail millet alone
T_{15}: Custard apple alone

Fig. 4.10: Total nitrogen content (mg kg^{-1}) in soil at different depths as influenced by custard apple based agri–horticulture system after harvest of crops

form of litter fall and its decomposition and also due to non–leguminous nature of all the components as a result of which there was no or a very less amount of atmospheric nitrogen fixation that further affect soil total nitrogen status. Similar results were reported by Vishal Johar *et al.* (2017). Similar trend was maintained at all depths of soil with higher values in treatments with legume crops.

According to pooled data, the total N content varied significantly at lower depths of soil. The treatment CA + Cowpea (T_6) (581.17, 518.26 and 391.49 mg kg^{-1}) maintained significantly higher total N at 15–30, 30–60 and 60–90 cm depth, respectively. Significantly lower total N content at 15–30, 30–60 and 60–90 cm depth was recorded in treatment Fodder maize alone (T_9) (416.71, 309.52 and 205.28 mg kg^{-1}, respectively). Higher content of total nitrogen at surface soil (0 -15 cm) might be due to presence of higher organic matter. Irrespective of the treatments, total N was decreased with increase in soil depth. The decrease in the total nitrogen content with increase in depth may be related to the close link with organic carbon and due to association of nitrogen with organic matter and adsorption of ammonical nitrogen on humus complex in the soil (Ravikumar and Somashekar, 2013). Purnananda *et al.* (2017) showed that soils under coconut land use system the total nitrogen content in the soils decreased with depth from 407.00 to 334.52 ppm.

4.6 Correlation studies between soil organic carbon and nitrogen fractions and CEC at 0–15 cm depth of soil

Correlation coefficient between soil organic carbon and nitrogen and their fractions at 0–15 cm depth of soil is presented in Table 4.19. Soil organic carbon had significant positive correlation with TC ($r=0.992^{**}$), MBC ($r=0.969^{**}$), WSC ($r=0.984^{**}$) and LC ($r=0.925^{**}$) except SIC ($r=-0.809^{**}$) which was significantly negatively correlated. Different pools of soil carbon showed significant and positive relationship with each other indicating a dynamic relationship of different pools of carbon in soil. Significant positive correlation of SOC with TC, MBC, WSC and LC might be attributed to inter conversion among different forms. These results are in conformity with the reports of Singh *et al.* (2003).

Table 4.19: Correlation matrix (r–value) between soil carbon and nitrogen fractions and CEC at 0–15 cm depth of soil

Parameters	SOC	CEC	SIC	TC	MBC	WSC	LC	AV.N	NH_4–N	NO_3–N	TN
SOC	1.000										
CEC	0.940**	1.000									
SIC	-0.809**	-0.796**	1.000								
TC	0.992**	0.926**	-0.728**	1.000							
MBC	0.969**	0.876**	-0.819**	0.953**	1.000						
WSC	0.984**	0.940**	-0.819**	0.970**	0.954**	1.000					
LC	0.925**	0.844**	-0.846**	0.895**	0.927**	0.950**	1.000				
AV.N	0.929**	0.842**	-0.783**	0.914**	0.899**	0.932**	0.918**	1.000			
NH_4–N	0.938**	0.864**	-0.855**	0.911**	0.953**	0.906**	0.856**	0.883**	1.000		
NO_3–N	0.962**	0.898**	-0.853**	0.938**	0.954**	0.963**	0.906**	0.940**	0.955**	1.000	
TN	0.943**	0.959**	-0.865**	0.914**	0.893**	0.948**	0.870**	0.897**	0.897**	0.944**	1.000

Note: * and ** indicate significance values at P=0.05 and 0.01 level, respectively. SOC–Soil organic carbon, CEC–Cation exchange capacity, SIC–Soil inorganic carbon, TC–Total carbon, MBC–Microbial biomass carbon, WSC–Water soluble carbon, LC–Labile carbon, AV.N–Available N, NH_4–N–Ammonical nitrogen, NO_3–N–Nitrate nitrogen and TN–Total nitrogen.

This correlation results indicated that there is a strong relationship among the different forms of labile organic carbon, might be attributed to inter conversion among different forms. Similar results are reported by Alvarez and Alvarez (2000). Liu *et al*. (2013) revealed that MBC and WSC concentrations increased linearly with increasing soil SOC content, suggesting that total organic matter content was a major determinant of the amount of MBC and WSC present.

Wei *et al.* (2008) reported that soil carbon fractions were significantly positively correlated with each other. It shows that the increase in organic carbon or addition of organic material contributes to all the organic C fractions, although the contribution may vary.

The nitrogen fractions like available N ($r=0.929^{**}$), NH_4-N ($r=0.938^{**}$), NO_3-N ($r=0.962^{**}$) and total nitrogen ($r=0.943^{**}$) shown significantly positive correlation with soil organic carbon suggests that soil organic matter is the major source of nitrogen and its fractions. Available nitrogen was significantly and positively correlated with NH_4–N ($r=0.883^{**}$), NO_3–N ($r=0.940^{**}$) and total nitrogen ($r=0.897^{**}$). The nitrogen fractions were significantly and positively correlated with each other showing their contribution to available pools. These results were in accordance with Singh (2009).

CEC had significantly positive correlation with SOC ($r=0.940^{**}$), TC ($r=0.926^{**}$), MBC ($r=0.876^{**}$), WSC ($r=0.940^{**}$), LC ($r=0.844^{**}$), available N ($r=0.842^{**}$), NH_4-N ($r=0.864^{**}$), NO_3-N ($r=0.989^{**}$) and total nitrogen ($r=0.959^{**}$) but was significantly negatively correlated with SIC ($r=-0.796^{**}$). Positive correlations between SOC and CEC suggest that soil organic carbon contributed to increase soil CEC (Papini *et al.,* 2011). Monisa Raza (2015) reported that CEC was positively correlated with total organic carbon, total carbon, water soluble carbon, microbial carbon, organic carbon, very labile and less labile carbon in the surface and subsurface layer.

On the other hand, the SIC had significantly negative correlation with other fractions of carbon like SOC ($r=-0.809^{**}$) TC ($r=-0.728^{**}$), MBC ($r=-0.819^{**}$), WSC ($r=-0.819^{**}$) and LC ($r=-0.846^{**}$) as well as with nitrogen fractions like available N

(r=-0.783**), NH_4-N (r=-0.855**), NO_3-N (r=-0.853**) and total nitrogen (r=-0.865**). Significantly negative correlation between SOC and SIC might be due to the fact that higher SOC in soil can produce higher CO_2 concentration in soil during decomposition of organic matter, which would lead to production of both HCO^-_3 and H^+. High level of H^+ would create acidic conditions in soil, thus reduce the carbonates, leading to a negative relationship between SOC and SIC (Shi *et al.,* 2017).

4.7 Effect of custard apple based agri–horticulture system on yield of crops during 2017 and 2018

4.7.1 Grain and straw yield of finger millet

The data on grain and straw yield of finger millet as influenced by custard apple based agri–horticulture system are presented in Table 4.20. Intercropping of CA + finger millet (T_1) recorded lower grain yield (1614 and 1605 kg ha^{-1}) as compared to finger millet alone (T_8) (2931 and 2628 kg ha^{-1}) during 2017 and 2018, respectively. Pooled data revealed that higher grain yield was recorded in finger millet alone (T_8) (2779 kg ha^{-1}) and lower was recorded in CA + finger millet (T_1) (1609 kg ha^{-1}).

Higher straw yield was recorded in finger millet alone (T_8) (3625 and 3638 kg ha^{-1}) during 2017 and 2018, respectively and lower was in CA + finger millet (T_1) (1861 and 1771 kg ha^{-1}). Pooled data revealed that higher straw yield was recorded in finger millet alone (T_8) (3632 kg ha^{-1}) and lower was recorded in CA + finger millet (T_1) (1816 kg ha^{-1}).

4.7.2 Green fodder yield of fodder maize

The data on green fodder yield of fodder maize as influenced by custard apple based agri–horticulture system are presented in Table 4.20. Higher green fodder yield was noticed in treatment T_9 (Fodder maize alone) (47744 and 45654 kg ha^{-1}) and lower was recorded in T_2 (CA + Fodder maize) (29454 and 28990 kg ha^{-1}) during 2017 and 2018, respectively. Pooled data showed that lower green fodder yield was recorded in T_2 (CA + Fodder maize) (28990 kg ha^{-1}) than T_9 (Fodder maize alone) (46699 kg ha^{-1}).

4.7.3 Grain and haulm yield of field bean

The data on grain and haulm yield of field bean as influenced by custard apple based agri–horticulture system is presented in Table 4.20. Field bean alone (T_{10}) recorded higher grain (726 and 741 kg ha^{-1}) and haulm (2474 and 2475 kg ha^{-1}) yield and lower grain (348 and 374 kg ha^{-1}) and haulm (1431 and 1316 kg ha^{-1}) yield was observed in CA + Field bean (T_3) during 2017 and 2018, respectively. In pooled data, higher grain and haulm yield was found in Field bean alone (T_{10}) (733 and 2475 kg ha^{-1}, respectively) and were lower in CA + Field bean (T_3) (361 and 1374 kg ha^{-1}, respectively).

4.7.4 Grain and stalk yield of niger

The data on grain and stalk yield of niger as influenced by custard apple based agri–horticulture system is presented in Table 4.20. Higher grain (289 and 305 kg ha^{-1}) and stalk (1571 and 1625 kg ha^{-1}) yields were recorded in Niger alone (T_{11}) and lower grain (186 and 204 kg ha^{-1}) and stalk (1016 and 1079 kg ha^{-1}) yield was observed in CA + Niger (T_4) during 2017 and 2018, respectively. In pooled data, higher grain and stalk yield was found in Niger alone (T_{11}) (297 and 1598 kg ha^{-1}, respectively) and were lower in CA + Niger (T_4) (195 and 1047 kg ha^{-1}, respectively).

4.7.5 Green chilli and stalk yield of chilli

The data on green chilli and stalk yield of chilli as influenced by custard apple based agri–horticulture system is presented in Table 4.20. Chilli alone (T_{12}) recorded higher green chilli (4157 and 4367 kg ha^{-1}) and stalk (2373 and 2399 kg ha^{-1}) yield and lower green chilli (2860 and 2766 kg ha^{-1}) and stalk (1731 ad 1723 kg ha^{-1}) yield was observed in CA + Chilli (T_5) during 2017 and 2018, respectively. In pooled data, higher green chilli and stalk yield was found in Chilli alone (T_{12}) (4262 and 2386 kg ha^{-1}, respectively) and were lower in CA + Chilli (T_5) (2813 and 1727 kg ha^{-1}, respectively).

4.7.6 Grain and haulm yield of cowpea

The data on grain and haulm yield of cowpea as influenced by custard apple based agri–horticulture system is presented in Table 4.20. Cowpea alone (T_{13}) recorded higher grain (837 and 842 kg ha^{-1}) and haulm (2446 and 2546 kg ha^{-1}) yield and lower grain

(375 and 395 kg ha^{-1}) and haulm (1050 and 1147 kg ha^{-1}) yield was observed in CA + Cowpea (T_6) during 2017 and 2018, respectively. In pooled data, higher grain and haulm yield was found in Cowpea alone (T_{13}) (840 and 2496 kg ha^{-1}, respectively) and were lower in CA + Cowpea (T_6) (385 and 1099 kg ha^{-1}, respectively).

4.7.7 Grain and straw yield of foxtail millet

The data on grain and straw yield of foxtail millet as influenced by custard apple based agri–horticulture system is presented in Table 4.20. Higher grain (813 and 1051 kg ha^{-1}) and straw (2615 and 2540 kg ha^{-1}) yields were recorded in Foxtail millet alone (T_{14}) and lower grain (397 and 430 kg ha^{-1}) and straw (1284 and 1178 kg ha^{-1}) yield was observed in CA + Foxtail millet (T_7) during 2017 and 2018, respectively. In pooled data, higher grain and straw yield was found in Foxtail millet alone (T_{14}) (932 and 2578 kg ha^{-1}, respectively) and were lower in CA + Foxtail millet (T_7) (414 and 1231 kg ha^{-1}, respectively).

Generally, with respect to individual crop, it was observed that higher biomass yield was recorded under sole crops than intercrops. The differences in the yield between sole crops and intercrops were mainly due to differences in the plant population. The decreased in yield under intercropping systems might be due to competition among the component crops for limited resources. Total dry matter production was significantly higher in sole crops and lower under intercropping at harvest. Similar results were put forth by Das *et al*. (2011) and Chauhan *et al.* (2013). Bheemaiah and Subrahmanyam (2001) and Srilakshmi (2003) reported that the yield of blackgram and cluster bean were significantly higher in their pure stands than in agri–horticultural intercropping system. Basavarajappa *et al.* (2003) revealed that significantly higher foxtail millet grain yield was recorded in sole crop than intercrop treatments.

4.8 Effect of custard apple based agri–horticulture system on yield and equivalent yield of custard apple during 2017 and 2018

4.8.1 Custard apple yield

The data on custard apple yield as influenced by custard apple based agri–horticulture system are presented in Table 4.20. At harvest, yield of custard apple differed significantly due to intercropping. During 2017 and 2018, significantly higher custard apple yield (4374 and 4396 kg ha^{-1}, respectively) was recorded under treatment T_{15} (Custard apple alone). However, it was found on par with CA + Cowpea (T_6) (4329 and 4375 kg ha^{-1}, respectively) followed by CA + Field bean (T_3) (4228 and 4345 kg ha^{-1}, respectively) and CA + Niger (T_4) (4144 and 4092 kg ha^{-1}, respectively). Significantly lower custard apple yield was registered by CA + Fodder maize (T_2) (3800 and 3932 kg ha^{-1}, respectively) during 2017 and 2018.

Pooled analysis of 2017 and 2018 data showed that Custard apple alone (T_{15}) recorded significantly higher yield (4385 kg ha^{-1}) of custard apple. However, it was on par with CA + Cowpea (T_6) (4352 kg ha^{-1}) and CA + Field bean (T_3) (4286 kg ha^{-1}). Significantly lower custard apple yield was recorded in CA + Fodder maize (T_2) (3866 kg ha^{-1}). Higher custard apple yield under custard apple alone (T_{15}) treatment might be due to non-existence of any competition for resources. Significant differences in the fruit yield might be attributed to variation in different yield components such as number of fruits $plant^{-1}$, fruit weight (g), fruit size (cm) and fruit volume (cc) at harvest. The variation in yield components of custard apple could also be attributed to the differences in biomass (Ramulu *et al.,* 2017). Since, additive plant population of intercrops resulted in increased competition for soil moisture and nutrients as well as atmospheric factors like light and this competition restricted the development of the plant as a whole in intercropping system. The reduction in fruit yield of custard apple under CA + Fodder maize was mainly attributed to competition for resources (Ramulu, 2014). The reduction in canopy spread of custard apple resulted in lower biomass in intercropped custard apple due to competition among the component crops for resources mainly moisture, nutrient, space and light. Olanyan and Fagbayide (2007) and Lal *et al*. (2011) also observed reduction in yield components due to intercropping systems.

Table 4.20: Yield of custard apple, intercrop, sole crop and custard apple equivalent yield as influenced by custard apple based agri–horticulture system during 2017 and 2018

Treatments	Custard apple yield			Intercrop and sole crop yield						Custard apple equivalent yield (CEY)		
				Grain yield			Straw yield					
	(kg ha^{-1})											
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1: CA + Finger millet	4024	4288	4156	1614	1605	1609	1861	1771	1816	807	856	831
T_2: CA + Fodder maize	3800	3932	3866	----	----	----	29454	28525	28990	490	475	483
T_3: CA + Field bean	4228	4345	4286	348	374	361	1431	1316	1374	243	312	277
T_4: CA + Niger	4144	4092	4118	186	204	195	1016	1079	1047	186	204	195
T_5: CA + Chilli	4113	4249	4181	2860	2766	2813	1731	1723	1727	715	737	726
T_6: CA + Cowpea	4329	4375	4352	375	395	385	1050	1147	1099	231	296	264
T_7: CA + Foxtail millet	4069	4175	4122	397	430	414	1284	1178	1231	185	215	200
T_8: Finger millet alone	----	----	----	2931	2628	2779	3625	3638	3632	----	----	----
T_9: Fodder maize alone	----	----	----	----	----	----	47744	45654	46699	----	----	----
T_{10}: Field bean alone	----	----	----	726	741	733	2474	2475	2475	----	----	----
T_{11}: Niger alone	----	----	----	289	305	297	1571	1625	1598	----	----	----
T_{12}: Chilli alone	----	----	----	4157	4367	4262	2373	2399	2386	----	----	----
T_{13}: Cowpea alone	----	----	----	837	842	840	2446	2546	2496	----	----	----
T_{14}: Foxtail millet alone	----	----	----	813	1051	932	2615	2540	2578	----	----	----
T_{15}: Custard apple alone	4374	4396	4385	----	----	----	----	----	----	----	----	----
S.Em ±	**96.88**	**89.97**	**68.70**	**----**	**----**	**----**	**----**	**----**	**----**	**28.40**	**29.75**	**14.44**
CD @ 5 %	**293.86**	**272.89**	**208.38**	**----**	**----**	**----**	**----**	**----**	**----**	**87.51**	**91.66**	**44.48**

Note: CA–Custard apple

4.8.2 Custard apple equivalent yield

Since different types of crops are included as intercrops in intercropping systems, it becomes very difficult to compare the economic produce of one system with the other. Hence, custard apple equivalent yield (CEY) was worked out for yield by considering the ratios of prices of crops as an index (Francis and Flor, 1976). The data on CEY as influenced by custard apple based agri–horticulture system is presented in Table 4.20. During 2017 and 2018, significantly higher CEY (807 and 856 kg ha^{-1}, respectively) was registered under CA + Finger millet (T_1) treatment followed by CA + Chilli (T_5) (715 and 737 kg ha^{-1}, respectively) and CA + Fodder maize (T_2) (490 and 475 kg ha^{-1}, respectively). Significantly lower CEY (185 kg ha^{-1}) was recorded in T_7 (CA + Foxtail millet) during 2017 and in T_4 (CA + Niger) (204 kg ha^{-1}) during 2018.

Pooled data showed that, CA + Finger millet (T_1) recorded significantly higher CEY (831 kg ha^{-1}) which was followed by CA + Chilli (T_5) (726 kg ha^{-1}) and CA + Fodder maize (T_2) (483 kg ha^{-1}). Significantly lower CEY (195 kg ha^{-1}) was recorded in T_4 (CA + Niger) however this was on par with T_3 (CA + Foxtail millet) (200 kg ha^{-1}). Higher custard apple equivalent yield under CA + Finger millet and CA + Chilli intercropping systems was attributed to yield advantages achieved in intercropping system. This is in accordance with the findings of Avinash Chandra Rathore *et al*. (2013). The difference in CEY was mainly due to differences in the yield and price of individual crops under intercropping system.

4.9 Assessment of efficiency of intercropping system

4.9.1 Land equivalent ratio

Land equivalent ratio (LER) varied significantly due to custard apple based agri–horticulture system (Table 4.21). The pooled data revealed that CA + Chilli (T_5) resulted in significantly higher LER (1.60) followed by CA + Niger (T_4) (1.58), CA + Finger millet (T_1) (1.49). CA + Fodder maize (T_2) (1.47), CA + Field bean (T_3) (1.45) and CA + Cowpea (T_6) (1.43) were found on par with each other. Significantly lower LER was recorded in Custard apple alone (T_{15}) (1.0). The LER of more than 1 shows the greater biological efficiency of intercropping systems. Land equivalent ratio (LER) indicates that

the relative land area under sole crop that is required to produce the yield achieved in the intercropping under the same level of management (Willey, 1979). Willey and Roberts (1976) reported that yield advantage in intercropping occurs when the component crops differ in their resource use pattern in such a way that, when they are grown in combination, they are able to complement each other to make better use of available resources than growing separately. Therefore, maximizing intercrop advantage is a matter of maximizing the degree of complementarity between the components and minimizing intercrop competition. Owere *et al.* (2001) recorded higher land equivalent ratio (LER) up to 1.30 and 1.29 in finger millet/pigeonpea and sorghum/pigeon pea intercropping at 2:2 row ratio.

4.9.2 Area time equivalent ratio

Area Time Equivalent Ratio (ATER) is the modification over LER where both land area and crop duration are considered to know the efficiency of intercropping system. The data on area time equivalent ratio (ATER) as influenced by custard apple based agri–horticulture system are indicated in Table 4.21. Area time equivalent ratio (ATER) differed significantly due to custard apple based agri–horticulture system. Pooled data revealed that CA + Chilli (T_5) registered significantly higher ATER (1.32) as compared to all other treatments, because the relative yield of intercrops was less as compared to custard apple alone. This result is in line with those of Prakasa Rao *et al.* (1988); Ofori and Stern (1987) and Sarkar and Shit (1990). However, it was on par with CA + Finger millet (T_1) (1.26). The treatments CA + Foxtail millet (T_7) (1.12), CA + Cowpea (T_6) (1.16), CA + Niger (T_4) (1.18) and CA + Field bean (T_3) (1.17) were found on par with each other. Significantly lower ATER was recorded by custard apple alone (T_{15}) (1.00) followed by CA + Fodder maize (T_2) (1.06). Sarkar and Shit (1990) observed higher ATER value (1.00) with maize + pigeonpea intercropping system followed by maize + soybean (0.85 ATER).

4.9.3 Rain water use efficiency

The data on rain water use efficiency (RWUE) of custard apple based agri–horticulture system is presented in Table 4.21. The pooled data revealed that CA +

Table 4.21: Land equivalent ratio (LER), area time equivalent ratio (ATER), Sustainable yield index (SYI) and rain water use efficiency (RWUE) of custard apple based agri–horticulture system

	LER			ATER			RWUE (kg ha–mm^{-1})			SYI
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**Pooled**
T_1: CA + Finger millet	1.45	1.52	1.49	1.23	1.29	1.26	6.13	14.03	10.08	0.99
T_2: CA + Fodder maize	1.47	1.48	1.47	1.04	1.08	1.06	5.44	12.03	8.73	1.00
T_3: CA + Field bean	1.42	1.47	1.45	1.16	1.19	1.17	5.67	12.70	9.19	0.97
T_4: CA + Niger	1.57	1.60	1.58	1.19	1.17	1.18	5.49	11.72	8.61	0.98
T_5: CA + Chilli	1.64	1.56	1.60	1.31	1.33	1.32	6.13	13.60	9.87	1.00
T_6: CA + Cowpea	1.42	1.44	1.43	1.15	1.17	1.16	5.79	12.74	9.26	0.99
T_7: CA + Foxtail millet	1.40	1.32	1.36	1.12	1.11	1.12	5.40	11.98	8.69	0.99
T_8: Finger millet alone	----	----	----	----	----	----	1.94	3.82	2.88	0.88
T_9: Fodder maize alone	----	----	----	----	----	----	1.08	2.08	1.58	0.95
T_{10}: Field bean alone	----	----	----	----	----	----	0.69	1.68	1.19	0.98
T_{11}: Niger alone	----	----	----	----	----	----	0.39	0.83	0.61	0.94
T_{12}: Chilli alone	----	----	----	----	----	----	1.38	3.18	2.28	0.94
T_{13}: Cowpea alone	----	----	----	----	----	----	0.70	1.72	1.21	0.99
T_{14}: Foxtail millet alone	----	----	----	----	----	----	0.51	1.43	0.97	0.73
T_{15}: Custard apple alone	1.00	1.00	1.00	1.00	1.00	1.00	5.55	11.99	8.77	0.99
S.Em ±	**0.06**	**0.03**	**0.04**	**0.04**	**0.04**	**0.03**	**----**	**----**	**----**	**----**
CD @ 5 %	**0.18**	**0.10**	**0.12**	**0.11**	**0.12**	**0.08**	**----**	**----**	**----**	**----**

Note: CA–Custard apple

Finger millet (T_1) recorded higher RWUE (10.08 kg ha-mm^{-1}) followed by CA + Chilli (T_5) (9.87 kg ha-mm^{-1}). However, next best RWUE was recorded by CA + Cowpea (T_6) (9.26 kg ha-mm^{-1}), CA + Field bean (T_3) (9.17 kg ha-mm^{-1}), Custard apple alone (T_{15}) (8.77 kg ha-mm^{-1}) and CA + Fodder maize (T_2) (8.73 kg ha-mm^{-1}). Lowest RWUE was registered by Niger alone (T_{11}) (0.61 kg ha-mm^{-1}). RWUE which helps in enhancing productivity by permitting better utilization of all other production factors and thus leads to increased yield per unit area and time. In the present study, there was clear indication of crop experiencing favourable soil moisture due to the inter cropping.

4.9.4 Sustainable yield index

The data on sustainable yield index (SYI) as influenced custard apple based agri–horticulture system is given in Table 4.21. Sustainable yield index varied due to intercropping. CA + Fodder maize (T_2) (1.00) and CA + Chilli (T_5) (1.00) recorded higher SYI as compared to all other treatments. Lower SYI was registered in Foxtail millet alone (T_{14}) (0.73) which was followed by Finger millet alone (T_7) (0.88). With respect to individual crops higher SYI was observed under intercropping systems than their respective sole crops. Higher SYI under intercropping systems was attributed to yield advantages achieved in intercropping system. The difference in SYI was mainly due to differences in the yield and price of individual component crops (Sekar *et al.*, 1993). Similar findings were reported by Maheswarappa (2008) who studied the biomass production and sustainable productivity of coconut *(Cocus nucifera* L.*)* based cropping system. Monoculture of coconut is less sustainable in terms of yield of main crop, besides an additional yield obtained through raising intercrop than intercropped coconut (Kikon *et al.,* 2012).

4.10 Effect of custard apple based agri–horticulture system on nutrient content (%) of crops during 2017 and 2018

4.10.1 Nutrient content of grain

Custard apple based agri–horticulture system significantly influenced the nutrient content of grain (green chillies in case of chilli crop) due to wide variation in crop species during 2017 and 2018.

Among primary nutrients significantly higher nitrogen and phosphorus content (Table 4.22) of grain was recorded in treatment CA + Field bean (T_3) which was on par T_{10} (Field bean alone), T_6 (CA + Cowpea) and T_{13} (Cowpea alone) during 2017 and 2018 as well in pooled data. Higher nitrogen content in treatments with legume components might be due to their capacity to fix atmospheric nitrogen and its accumulation in grains. Significantly higher potassium content was recorded in treatments Chilli alone (T_{12}) and CA + Chilli (T_5) during 2017 and 2018 as well in pooled data. Significantly lower nitrogen and phosphorus content of grain was registered in treatment CA + Foxtail millet (T_7) however, potassium content was found lower under T_8 (Finger millet alone).

Secondary nutrients content of grain varied significantly among the treatments during 2017 and 2018 as well in pooled data (Table 4.23). Among secondary nutrients, field bean treatments (T_3 and T_{10}) registered significantly higher calcium content in grain followed by cowpea (T_6 and T_{13}) and niger (T_4 and T_{11}) treatments during 2017 and 2018 as well in pooled data. Magnesium content during 2017 and 2018 as well in pooled data was found to be higher in cowpea (T_6 and T_{13}) treatments. Whereas, Sulphur content was higher under niger (T_4 and T_{11}) treatments during 2017 and 2018 as well in pooled data. Significantly lower calcium, magnesium and sulphur content of grain was recorded in foxtail millet (T_7 and T_{14}) treatments during 2017 and 2018 as well in pooled data.

Micronutrients (Fe, Mn, Zn and Cu) content of grain varied significantly among the treatments during 2017 and 2018 as well in pooled data (Table 4.24). Significantly higher Fe and Mn content were recorded under finger millet (T_1 and T_8) treatments. Foxtail millet (T7 and T14) treatments recorded significantly higher Zn content in grain. However, higher Cu content was noticed chilli (T_5 and T_{12}) treatments. Significantly lower Fe and Mn content were recorded under cowpea (T_6 and T_{13}) treatments. Whereas, Zn content was found lower under finger millet (T_1 and T_8) treatments. However foxtail millet (T_7 and T_{14}) treatments registered significantly lower Cu content in grain.

4.10.2 Nutrient content of straw/stalk/haulm

Custard apple based agri–horticulture system significantly influenced the nutrient content of straw/stalk/haulm due to wide variation in crop species during 2017 and 2018.

Table 4.22: Total nitrogen, phosphorus and potassium content in grain as influenced by custard apple based agri–horticulture system during 2017 and 2018

Treatments	Nitrogen			Phosphorus			Potassium		
	(%)								
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
T_1: CA + Finger millet	1.36	1.36	1.36	0.32	0.33	0.33	0.43	0.44	0.44
T_2: CA + Fodder maize	-----	-----	-----	-----	-----	-----	-----	-----	-----
T_3: CA + Field bean	2.24	2.24	2.24	0.58	0.60	0.59	1.18	1.21	1.20
T_4: CA + Niger	2.06	2.01	2.04	0.48	0.45	0.47	1.28	1.28	1.28
T_5: CA + Chilli*	1.77	1.79	1.78	0.35	0.36	0.36	1.32	1.34	1.33
T_6: CA + Cowpea	2.19	2.17	2.18	0.56	0.54	0.55	1.12	1.11	1.12
T_7: CA + Foxtail millet	1.17	1.19	1.18	0.29	0.29	0.29	0.57	0.60	0.59
T_8: Finger millet alone	1.34	1.33	1.34	0.31	0.29	0.30	0.44	0.42	0.43
T_9: Fodder maize alone	-----	-----	-----	-----	-----	-----	-----	-----	-----
T_{10}: Field bean alone	2.22	2.23	2.23	0.55	0.56	0.56	1.16	1.18	1.17
T_{11}: Niger alone	2.02	2.05	2.04	0.47	0.44	0.46	1.25	1.26	1.26
T_{12}: Chilli alone*	1.76	1.72	1.74	0.32	0.32	0.32	1.34	1.33	1.34
T_{13}: Cowpea alone	2.18	2.18	2.18	0.53	0.55	0.54	1.13	1.15	1.14
T_{14}: Foxtail millet alone	1.19	1.21	1.20	0.30	0.31	0.31	0.56	0.60	0.58
T_{15}: Custard apple alone	-----	-----	-----	-----	-----	-----	-----	-----	-----
S.Em ±	**0.052**	**0.053**	**0.052**	**0.019**	**0.020**	**0.019**	**0.046**	**0.047**	**0.047**
CD @ 5 %	**0.153**	**0.156**	**0.154**	**0.056**	**0.057**	**0.057**	**0.135**	**0.139**	**0.137**

Note: *Nutrient content in green chillies
CA–Custard apple

Table 4.23: Total calcium, magnesium and sulphur content in grain as influenced by custard apple based agri–horticulture system during 2017 and 2018

Treatments	Calcium			Magnesium			Sulphur		
	(%)								
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
T_1: CA + Finger millet	0.48	0.51	0.50	0.31	0.35	0.33	0.17	0.21	0.19
T_2: CA + Fodder maize	-----	-----	-----	-----	-----	-----	-----	-----	-----
T_3: CA + Field bean	0.92	0.90	0.91	0.60	0.58	0.59	0.27	0.25	0.26
T_4: CA + Niger	0.79	0.82	0.81	0.63	0.59	0.61	0.85	0.84	0.85
T_5: CA + Chilli*	0.65	0.68	0.66	0.51	0.55	0.53	0.27	0.29	0.28
T_6: CA + Cowpea	0.82	0.84	0.83	0.73	0.73	0.73	0.31	0.32	0.32
T_7: CA + Foxtail millet	0.30	0.32	0.31	0.21	0.19	0.20	0.16	0.18	0.17
T_8: Finger millet alone	0.49	0.47	0.48	0.31	0.35	0.33	0.19	0.20	0.20
T_9: Fodder maize alone	-----	-----	-----	-----	-----	-----	-----	-----	-----
T_{10}: Field bean alone	0.90	0.89	0.90	0.58	0.58	0.58	0.28	0.31	0.30
T_{11}: Niger alone	0.81	0.85	0.83	0.64	0.63	0.63	0.84	0.85	0.85
T_{12}: Chilli alone*	0.66	0.63	0.64	0.52	0.55	0.54	0.25	0.26	0.26
T_{13}: Cowpea alone	0.83	0.83	0.83	0.71	0.74	0.73	0.31	0.34	0.33
T_{14}: Foxtail millet alone	0.30	0.28	0.29	0.32	0.33	0.33	0.15	0.18	0.17
T_{15}: Custard apple alone	-----	-----	-----	-----	-----	-----	-----	-----	-----
S.Em ±	**0.031**	**0.031**	**0.031**	**0.024**	**0.024**	**0.024**	**0.016**	**0.016**	**0.016**
CD @ 5 %	**0.091**	**0.091**	**0.091**	**0.069**	**0.071**	**0.070**	**0.047**	**0.048**	**0.047**

Note: *Nutrient content in green chillies
CA–Custard apple

Table 4.24: Micronutrients content in grain as influenced by custard apple based agri–horticulture system during 2017 and 2018

Treatments	Fe			Mn			Zn			Cu		
	(mg kg^{-1})											
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
T_1: CA + Finger millet	150.32	158.26	154.29	98.20	104.35	101.27	23.46	23.89	23.68	7.95	8.65	8.30
T_2: CA + Fodder maize	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
T_3: CA + Field bean	89.75	95.35	92.55	43.29	44.35	43.82	25.42	30.46	27.94	9.09	8.96	9.03
T_4: CA + Niger	92.06	101.43	96.75	53.47	60.34	56.91	31.18	28.74	29.96	6.68	6.79	6.73
T_5: CA + Chilli*	128.32	134.48	131.40	86.04	92.47	89.26	35.94	33.81	34.87	9.16	9.24	9.20
T_6: CA + Cowpea	84.52	80.17	82.35	38.16	36.81	37.49	21.63	26.85	24.24	8.97	9.06	9.02
T_7: CA + Foxtail millet	112.24	106.34	109.29	77.49	79.09	78.29	40.98	38.94	39.96	5.43	5.26	5.34
T_8: Finger millet alone	156.42	150.79	153.61	95.34	90.88	93.11	27.56	25.99	26.78	7.74	7.54	7.64
T_9: Fodder maize alone	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
T_{10}: Field bean alone	92.32	95.74	94.03	45.75	50.38	48.07	23.38	28.45	25.92	8.99	8.73	8.86
T_{11}: Niger alone	90.34	96.08	93.21	50.34	56.49	53.42	33.45	36.17	34.81	6.53	6.71	6.62
T_{12}: Chilli alone*	134.62	129.34	131.98	90.35	92.78	91.57	34.63	38.43	36.53	9.24	9.06	9.15
T_{13}: Cowpea alone	86.04	88.49	87.27	42.15	43.36	42.76	24.37	26.73	25.55	8.93	9.01	8.97
T_{14}: Foxtail millet alone	110.45	119.84	115.15	76.43	80.76	78.60	40.05	45.38	42.72	5.53	5.26	5.40
T_{15}: Custard apple alone	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
S.Em ±	**5.319**	**5.407**	**5.361**	**3.317**	**3.442**	**3.379**	**1.424**	**1.516**	**1.468**	**0.367**	**0.367**	**0.367**
CD @ 5 %	**15.601**	**15.857**	**15.724**	**9.729**	**10.095**	**9.909**	**4.176**	**4.446**	**4.306**	**1.078**	**1.077**	**1.077**

Note: *Nutrient content in green chillies
CA–Custard apple

Among primary nutrients significantly higher nitrogen and phosphorus content (Table 4.25) was recorded in haulm of field bean (T_3 and T_{10}) and Cowpea (T_6 and T_{13}) treatments during 2017 and 2018 as well in pooled data. Higher nitrogen content in treatments with legume components might be due to their capacity to fix atmospheric nitrogen and its utilization for growth of plant. Significantly higher potassium content was recorded in stalk of niger (T_{11} and T_4) treatments. Significantly lower nitrogen content was registered in stalk of foxtail millet (T_7 and T_{14}) treatments and lower phosphorus was recorded in straw of foxtail millet (T_7 and T_{14}) treatments however, potassium content was found lower under fodder maize (T_2 and T_9) treatments.

Secondary nutrients content of straw/stalk/haulm varied significantly among the treatments during 2017 and 2018 as well in pooled data (Table 4.26). Among secondary nutrients, significantly higher calcium content was found in haulm of field bean (T_3 and T_{10}) and Cowpea (T_6 and T_{13}) treatments during 2017 and 2018 as well in pooled data. Magnesium content during 2017 and 2018 as well in pooled data was found to be higher in haulm of field bean (T_3 and T_{10}) treatments. Whereas, Sulphur content was higher under niger (T_4 and T_{11}) treatments during 2017 and 2018 as well in pooled data. Significantly lower calcium, magnesium content was recorded in fodder maize treatments (T_9 and T_2) and sulphur content was recorded low in foxtail millet (T_7 and T_{14}) treatments during 2017 and 2018 as well in pooled data.

Micronutrients (Fe, Mn, Zn and Cu) content of straw/stalk/haulm varied significantly among the treatments during 2017 and 2018 as well in pooled data (Table 4.27). Significantly higher Fe content was found in fodder maize (T_2 and T_9) treatments and higher Mn content was recorded in stalk of chilli (T_5 and T_{12}) treatments. Foxtail millet (T_7 and T_{14}) treatments recorded significantly higher Zn content in straw. However, higher Cu content was noticed chilli (T_5 and T_{12}) treatments. Significantly lower Fe, Mn and Zn content were contained in haulm of cowpea (T_6 and T_{13}) and field bean (T_3 and T_{10}) treatments. Whereas, Cu content was found lower in foxtail millet (T_7 and T_{14}) treatments during 2017 and 2018 as well in pooled data.

Table 4.25: Total nitrogen, phosphorus and potassium content in straw as influenced by custard apple based agri–horticulture system during 2017 and 2018

Treatments	Nitrogen			Phosphorus			Potassium		
	(%)								
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
T_1: CA + Finger millet	1.09	1.19	1.14	0.24	0.26	0.25	1.13	1.16	1.15
T_2: CA + Fodder maize	1.02	1.10	1.06	0.29	0.32	0.31	0.97	1.06	1.02
T_3: CA + Field bean	1.50	1.42	1.46	0.35	0.38	0.37	1.74	1.79	1.77
T_4: CA + Niger	0.78	0.81	0.80	0.22	0.26	0.24	1.84	1.83	1.84
T_5: CA + Chilli	0.98	1.02	1.00	0.23	0.20	0.22	1.56	1.61	1.59
T_6: CA + Cowpea	1.28	1.39	1.34	0.21	0.21	0.21	1.81	1.78	1.80
T_7: CA + Foxtail millet	0.64	0.68	0.66	0.13	0.16	0.15	1.12	1.16	1.14
T_8: Finger millet alone	1.11	1.23	1.17	0.25	0.22	0.24	1.15	1.14	1.15
T_9: Fodder maize alone	1.02	1.20	1.11	0.28	0.29	0.29	1.01	1.06	1.03
T_{10}: Field bean alone	1.42	1.40	1.41	0.32	0.29	0.31	1.71	1.75	1.73
T_{11}: Niger alone	0.79	0.82	0.81	0.25	0.26	0.26	1.87	1.91	1.89
T_{12}: Chilli alone	0.95	0.95	0.95	0.26	0.23	0.25	1.60	1.63	1.61
T_{13}: Cowpea alone	1.30	1.22	1.26	0.22	0.20	0.21	1.84	1.88	1.86
T_{14}: Foxtail millet alone	0.62	0.59	0.61	0.12	0.16	0.14	1.15	1.16	1.16
T_{15}: Custard apple alone	-----	-----	-----	-----	-----	-----	-----	-----	-----
S.Em ±	**0.04**	**0.05**	**0.04**	**0.01**	**0.01**	**0.01**	**0.07**	**0.07**	**0.07**
CD @ 5 %	**0.12**	**0.15**	**0.13**	**0.03**	**0.03**	**0.03**	**0.20**	**0.20**	**0.20**

Note: CA–Custard apple

Table 4.26: Total calcium, magnesium and sulphur content in straw as influenced by custard apple based agri–horticulture system during 2017 and 2018

Treatments	Calcium			Magnesium			Sulphur		
	(%)								
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
T_1: CA + Finger millet	0.85	0.86	0.86	0.63	0.66	0.65	0.27	0.31	0.29
T_2: CA + Fodder maize	0.35	0.39	0.37	0.14	0.19	0.16	0.19	0.16	0.17
T_3: CA + Field bean	1.21	1.18	1.20	0.69	0.66	0.68	0.24	0.22	0.23
T_4: CA + Niger	0.98	0.95	0.97	0.64	0.64	0.64	0.53	0.59	0.56
T_5: CA + Chilli	0.81	0.86	0.84	0.66	0.69	0.67	0.20	0.25	0.23
T_6: CA + Cowpea	1.17	1.20	1.19	0.62	0.59	0.61	0.22	0.20	0.21
T_7: CA + Foxtail millet	0.46	0.45	0.46	0.23	0.26	0.25	0.15	0.16	0.16
T_8: Finger millet alone	0.88	0.89	0.89	0.63	0.60	0.62	0.29	0.32	0.30
T_9: Fodder maize alone	0.32	0.31	0.31	0.13	0.14	0.14	0.16	0.20	0.18
T_{10}: Field bean alone	1.24	1.28	1.26	0.70	0.69	0.70	0.22	0.22	0.22
T_{11}: Niger alone	0.99	0.96	0.98	0.62	0.68	0.65	0.53	0.57	0.55
T_{12}: Chilli alone	0.82	0.79	0.81	0.67	0.71	0.69	0.21	0.19	0.20
T_{13}: Cowpea alone	1.15	1.20	1.18	0.62	0.58	0.60	0.25	0.25	0.25
T_{14}: Foxtail millet alone	0.44	0.47	0.46	0.25	0.29	0.27	0.17	0.19	0.18
T_{15}: Custard apple alone	-----	-----	-----	-----	-----	-----	-----	-----	-----
S.Em ±	**0.04**	**0.04**	**0.04**	**0.03**	**0.03**	**0.03**	**0.01**	**0.01**	**0.01**
CD @ 5 %	**0.12**	**0.12**	**0.12**	**0.07**	**0.07**	**0.07**	**0.04**	**0.04**	**0.04**

Note: CA–Custard apple

Table 4.27: Micronutrients content in straw as influenced by custard apple based agri–horticulture system during 2017 and 2018

Treatments	Fe			Mn			Zn			Cu		
	(mg kg^{-1})											
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
T_1: CA + Finger millet	130.27	136.27	133.27	60.32	65.37	62.85	38.26	42.31	40.29	6.76	7.01	6.89
T_2: CA + Fodder maize	162.43	170.26	166.35	42.67	40.34	41.51	39.61	39.08	39.34	7.35	7.26	7.31
T_3: CA + Field bean	90.03	95.47	92.75	43.72	48.62	46.17	23.74	25.18	24.46	8.52	8.44	8.48
T_4: CA + Niger	102.33	99.28	100.81	62.53	62.31	62.42	38.70	41.66	40.18	8.11	8.27	8.19
T_5: CA + Chilli	139.67	145.73	142.70	101.32	105.43	103.38	51.43	48.37	49.90	8.66	9.02	8.84
T_6: CA + Cowpea	83.53	90.37	86.95	39.54	36.47	38.01	20.37	24.29	22.33	8.64	8.73	8.69
T_7: CA + Foxtail millet	110.28	117.17	113.72	67.29	71.18	69.23	58.43	54.88	56.65	5.89	6.11	6.00
T_8: Finger millet alone	132.34	130.41	131.37	64.75	64.09	64.42	46.26	43.84	45.05	6.64	6.38	6.51
T_9: Fodder maize alone	165.42	170.24	167.83	40.96	43.07	42.02	37.46	39.17	38.32	7.26	7.09	7.18
T_{10}: Field bean alone	95.74	90.63	93.19	48.37	52.73	50.55	26.89	28.34	27.62	8.59	8.44	8.51
T_{11}: Niger alone	100.85	106.34	103.60	63.84	68.46	66.15	38.16	35.91	37.04	8.25	8.39	8.32
T_{12}: Chilli alone	143.76	151.47	147.62	105.34	110.49	107.92	54.24	53.88	54.06	8.67	8.35	8.51
T_{13}: Cowpea alone	88.63	89.21	88.92	42.09	38.41	40.25	25.08	29.74	27.41	8.82	8.61	8.71
T_{14}: Foxtail millet alone	113.79	109.75	111.77	65.38	66.08	65.73	59.34	62.44	60.89	5.96	6.21	6.09
T_{15}: Custard apple alone	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
S.Em ±	**5.91**	**6.07**	**5.99**	**3.02**	**3.33**	**3.17**	**2.00**	**2.02**	**2.01**	**0.36**	**0.36**	**0.36**
CD @ 5 %	**17.17**	**17.66**	**17.41**	**8.79**	**9.68**	**9.20**	**5.81**	**5.86**	**5.83**	**1.05**	**1.05**	**1.05**

Note: CA–Custard apple

4.11 Effect of custard apple based agri–horticulture system on nutrient uptake (kg ha^{-1}) of crops during 2017 and 2018

4.11.1 Nutrient uptake by grain

Custard apple based agri–horticulture system significantly influenced the primary, secondary and micronutrient uptake of grain (green chillies in case of chilli crop) due to different crops due to variation in yield during 2017 and 2018. Generally, sole crops recorded higher nutrient uptake than their respective intercrops (Table 4.28, 4.29 and 4.30).

In both sole crop and intercropping system chilli treatments (T_{12} and T_5) recorded significantly higher uptake of all nutrients (in green chilli) than other treatments which was followed by finger millet treatments (T_8 and T_1) during 2017 and 2018 as well as in pooled data. Significantly lower uptake of all nutrients was recorded with niger (T_4 and T_{11}) except secondary nutrients which were found lower in foxtail millet treatments (T_7 and T_{14}).

4.11.2 Nutrient uptake by straw/stalk/haulm

Custard apple based agri–horticulture system significantly influenced the primary, secondary and micronutrient uptake of straw/stalk/haulm due to different crops due to variation in yield during 2017 and 2018. Generally, sole crops recorded higher nutrient uptake than their respective intercrops (Table 4.31, 4.32 and 4.33).

In both sole crop and intercropping systems fodder maize treatments (T_9 and T_2) recorded significantly higher uptake of all nutrients than other treatments during 2017 and 2018 as well as in pooled data. Significantly lower uptake of all nutrients was recorded under treatments with foxtail millet (T_7 and T_{14}), niger (T_4 and T_{11}) and cowpea (T_6 and T_{13}) during 2017 and 2018 as well as in pooled data.

Table 4.28: Nitrogen, phosphorus and potassium uptake by grain as influenced by custard apple based agri–horticulture system during 2017 and 2018

Treatments	Nitrogen			Phosphorus			Potassium		
	(kg ha^{-1})								
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
T_1: CA + Finger millet	21.92	21.82	21.87	5.17	5.29	5.23	7.00	7.05	7.03
T_2: CA + Fodder maize	-----	-----	-----	-----	-----	-----	-----	-----	-----
T_3: CA + Field bean	7.80	8.41	8.10	2.03	2.23	2.13	4.13	4.52	4.32
T_4: CA + Niger	3.84	4.10	3.97	0.90	0.92	0.91	2.38	2.61	2.50
T_5: CA + Chilli*	33.03	49.65	41.34	6.59	9.99	8.29	24.69	37.26	30.98
T_6: CA + Cowpea	8.22	8.57	8.40	2.09	2.15	2.12	4.14	4.40	4.27
T_7: CA + Foxtail millet	4.67	5.16	4.91	1.14	1.24	1.19	2.29	2.59	2.44
T_8: Finger millet alone	39.37	34.89	37.13	9.08	7.61	8.34	12.78	11.01	11.90
T_9: Fodder maize alone	-----	-----	-----	-----	-----	-----	-----	-----	-----
T_{10}: Field bean alone	16.13	16.55	16.34	4.01	4.13	4.07	8.47	8.71	8.59
T_{11}: Niger alone	5.85	6.27	6.06	1.36	1.35	1.36	3.63	3.86	3.74
T_{12}: Chilli alone*	49.88	75.18	62.53	9.07	13.99	11.53	37.98	58.14	48.06
T_{13}: Cowpea alone	18.22	18.34	18.28	4.42	4.63	4.53	9.42	9.68	9.55
T_{14}: Foxtail millet alone	9.60	12.71	11.16	2.42	3.26	2.84	4.52	6.33	5.43
T_{15}: Custard apple alone	-----	-----	-----	-----	-----	-----	-----	-----	-----
S.Em ±	**1.79**	**2.00**	**1.68**	**0.38**	**0.42**	**0.34**	**1.19**	**1.39**	**1.19**
CD @ 5 %	**5.25**	**5.88**	**4.93**	**1.12**	**1.22**	**1.01**	**3.50**	**4.06**	**3.49**

Note: *Nutrient uptake in green chillies
CA–Custard apple

Table 4.29: Calcium, magnesium and sulphur uptake by grain as influenced by custard apple based agri–horticulture system during 2017 and 2018

Treatments	Calcium			Magnesium			Sulphur		
	(kg ha^{-1})								
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1: CA + Finger millet	7.75	8.18	7.97	5.06	5.61	5.34	2.75	3.31	3.03
T_2: CA + Fodder maize	-----	-----	-----	-----	-----	-----	-----	-----	-----
T_3: CA + Field bean	3.21	3.36	3.29	2.09	2.17	2.13	0.93	0.94	0.94
T_4: CA + Niger	1.47	1.67	1.57	1.17	1.20	1.19	1.58	1.71	1.65
T_5: CA + Chilli*	12.07	18.76	15.42	9.52	15.25	12.39	5.04	8.04	6.54
T_6: CA + Cowpea	3.02	3.33	3.18	2.70	2.89	2.80	1.16	1.27	1.21
T_7: CA + Foxtail millet	1.18	1.38	1.28	0.85	0.84	0.84	0.64	0.78	0.71
T_8: Finger millet alone	14.34	12.32	13.33	9.08	9.17	9.13	5.55	5.23	5.39
T_9: Fodder maize alone	-----	-----	-----	-----	-----	-----	-----	-----	-----
T_{10}: Field bean alone	6.57	6.57	6.57	4.23	4.28	4.26	2.04	2.29	2.17
T_{11}: Niger alone	2.34	2.60	2.47	1.84	1.92	1.88	2.43	2.60	2.52
T_{12}: Chilli alone*	18.71	27.40	23.06	14.75	24.04	19.40	7.18	11.51	9.35
T_{13}: Cowpea alone	6.93	6.99	6.96	5.92	6.26	6.09	2.59	2.86	2.72
T_{14}: Foxtail millet alone	2.42	2.94	2.68	2.61	3.50	3.05	1.21	1.89	1.55
T_{15}: Custard apple alone	-----	-----	-----	-----	-----	-----	-----	-----	-----
S.Em ±	**0.70**	**0.72**	**0.63**	**0.53**	**0.61**	**0.51**	**0.26**	**0.30**	**0.25**
CD @ 5 %	**2.05**	**2.10**	**1.84**	**1.56**	**1.78**	**1.51**	**0.77**	**0.89**	**0.74**

Note: *Nutrient uptake in green chillies
CA–Custard apple

Table 4.30: Micronutrients uptake by grain as influenced by custard apple based agri–horticulture system during 2017 and 2018

Treatments	Fe			Mn			Zn			Cu		
	(g ha^{-1})											
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
T_1: CA + Finger millet	242.80	253.75	248.28	158.61	167.31	162.96	37.89	38.30	38.10	12.84	13.87	13.36
T_2: CA + Fodder maize	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
T_3: CA + Field bean	31.40	35.59	33.50	15.14	16.55	15.85	8.89	11.37	10.13	3.18	3.34	3.26
T_4: CA + Niger	17.15	20.68	18.91	9.96	12.30	11.13	5.81	5.86	5.84	1.24	1.38	1.31
T_5: CA + Chilli*	239.45	372.98	306.21	160.54	256.47	208.51	67.06	93.77	80.42	17.09	25.63	21.36
T_6: CA + Cowpea	31.30	31.76	31.53	14.13	14.59	14.36	8.01	10.64	9.33	3.32	3.59	3.46
T_7: CA + Foxtail millet	44.75	45.96	45.35	30.89	34.18	32.54	16.34	16.83	16.58	2.16	2.27	2.22
T_8: Finger millet alone	457.79	395.25	426.52	279.02	238.21	258.62	80.67	68.13	74.40	22.65	19.76	21.21
T_9: Fodder maize alone	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
T_{10}: Field bean alone	67.40	70.66	69.03	33.40	37.18	35.29	17.07	21.00	19.03	6.56	6.44	6.50
T_{11}: Niger alone	26.14	29.40	27.77	14.57	17.29	15.93	9.68	11.07	10.38	1.89	2.05	1.97
T_{12}: Chilli alone*	381.58	565.37	473.48	256.10	405.56	330.83	98.15	167.99	133.07	26.19	39.59	32.89
T_{13}: Cowpea alone	71.78	74.50	73.14	35.16	36.50	35.83	20.33	22.51	21.42	7.44	7.58	7.51
T_{14}: Foxtail millet alone	89.09	125.86	107.48	61.65	84.82	73.24	32.31	47.66	39.98	4.46	5.53	4.99
T_{15}: Custard apple alone	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
S.Em ±	**15.47**	**15.62**	**13.68**	**10.05**	**10.73**	**9.18**	**3.54**	**4.03**	**3.41**	**0.97**	**1.02**	**0.89**
CD @ 5 %	**45.37**	**45.82**	**40.11**	**29.48**	**31.46**	**26.92**	**10.39**	**11.83**	**10.01**	**2.85**	**3.00**	**2.60**

Note: *Nutrient uptake in green chillies
CA–Custard apple

Table 4.31: Nitrogen, phosphorus and potassium uptake by straw as influenced by custard apple based agri–horticulture system during 2017 and 2018

Treatments	Nitrogen			Phosphorus			Potassium		
	(kg ha^{-1})								
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1: CA + Finger millet	20.37	21.10	20.73	4.42	4.68	4.55	21.10	20.62	20.86
T_2: CA + Fodder maize	81.21	81.77	81.49	23.38	23.79	23.59	77.33	78.78	78.06
T_3: CA + Field bean	21.27	18.72	19.99	5.00	5.01	5.01	24.92	23.59	24.26
T_4: CA + Niger	7.89	8.75	8.32	2.23	2.81	2.52	18.63	19.77	19.20
T_5: CA + Chilli	16.94	17.64	17.29	3.97	3.46	3.72	26.97	27.90	27.44
T_6: CA + Cowpea	13.51	16.01	14.76	2.23	2.42	2.32	19.15	20.50	19.83
T_7: CA + Foxtail millet	8.19	8.00	8.09	1.66	1.88	1.77	14.34	13.64	13.99
T_8: Finger millet alone	40.27	44.51	42.39	9.15	7.96	8.55	41.64	41.26	41.45
T_9: Fodder maize alone	121.38	125.97	123.68	34.60	30.37	32.49	120.36	110.61	115.49
T_{10}: Field bean alone	35.07	34.76	34.92	7.90	7.18	7.54	42.24	43.43	42.83
T_{11}: Niger alone	12.43	13.37	12.90	3.98	4.24	4.11	29.41	31.14	30.27
T_{12}: Chilli alone	22.66	22.74	22.70	6.28	5.51	5.89	38.16	38.94	38.55
T_{13}: Cowpea alone	31.72	30.93	31.33	5.38	5.07	5.22	44.98	47.67	46.33
T_{14}: Foxtail millet alone	16.33	15.05	15.69	3.14	4.09	3.62	30.15	29.62	29.88
T_{15}: Custard apple alone	-----	-----	-----	-----	-----	-----	-----	-----	-----
S.Em ±	**2.18**	**2.48**	**2.06**	**0.65**	**0.62**	**0.59**	**3.15**	**2.63**	**2.71**
CD @ 5 %	**6.35**	**7.20**	**5.99**	**1.89**	**1.80**	**1.71**	**9.17**	**7.65**	**7.89**

Note: CA–Custard apple

Table 4.32: Calcium, magnesium and sulphur uptake by straw as influenced by custard apple based agri–horticulture system during 2017 and 2018

Treatments	Calcium			Magnesium			Sulphur		
	(kg ha^{-1})								
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
T_1: CA + Finger millet	15.88	15.29	15.58	11.76	11.73	11.75	5.11	5.57	5.34
T_2: CA + Fodder maize	27.89	28.98	28.44	11.17	13.88	12.53	14.89	11.89	13.39
T_3: CA + Field bean	17.30	15.55	16.43	9.86	8.70	9.28	3.44	2.90	3.17
T_4: CA + Niger	9.92	10.26	10.09	6.44	6.88	6.66	5.36	6.37	5.87
T_5: CA + Chilli	14.00	14.87	14.44	11.36	11.94	11.65	3.46	4.33	3.90
T_6: CA + Cowpea	12.42	13.82	13.12	6.56	6.80	6.68	2.33	2.31	2.32
T_7: CA + Foxtail millet	5.89	5.29	5.59	2.99	3.02	3.00	1.92	1.88	1.90
T_8: Finger millet alone	31.77	32.21	31.99	22.75	21.71	22.23	10.47	11.46	10.96
T_9: Fodder maize alone	38.13	32.10	35.12	15.48	14.64	15.06	19.06	21.29	20.18
T_{10}: Field bean alone	30.62	31.71	31.17	17.29	17.09	17.19	5.43	5.45	5.44
T_{11}: Niger alone	15.57	15.65	15.61	9.70	11.09	10.39	8.33	9.29	8.81
T_{12}: Chilli alone	19.63	18.99	19.31	15.98	17.00	16.49	4.93	4.47	4.70
T_{13}: Cowpea alone	28.12	30.43	29.27	15.16	14.71	14.93	6.11	6.34	6.23
T_{14}: Foxtail millet alone	11.54	12.00	11.77	6.55	7.40	6.98	4.46	4.85	4.66
T_{15}: Custard apple alone	-----	-----	-----	-----	-----	-----	-----	-----	-----
S.Em ±	**1.40**	**1.25**	**1.21**	**0.85**	**0.77**	**0.72**	**0.58**	**0.47**	**0.48**
CD @ 5 %	**4.08**	**3.64**	**3.51**	**2.48**	**2.23**	**2.10**	**1.69**	**1.38**	**1.40**

Note: CA–Custard apple

Table 4.33: Micronutrients uptake by straw as influenced by custard apple based agri–horticulture system during 2017 and 2018

Treatments	Fe			Mn			Zn			Cu		
	(g ha^{-1})											
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
T_1: CA + Finger millet	243.29	242.26	242.77	112.65	116.21	114.43	71.46	75.22	73.34	12.63	12.46	12.55
T_2: CA + Fodder maize	1294.94	1265.61	1280.28	340.17	299.86	320.02	315.78	290.47	303.12	58.59	53.99	56.29
T_3: CA + Field bean	128.70	125.84	127.27	62.50	64.09	63.29	33.94	33.19	33.57	12.18	11.13	11.65
T_4: CA + Niger	103.59	107.22	105.41	63.30	67.30	65.30	39.18	44.99	42.08	8.21	8.93	8.57
T_5: CA + Chilli	241.51	252.01	246.76	175.21	182.32	178.76	88.93	83.65	86.29	14.97	15.60	15.28
T_6: CA + Cowpea	88.42	104.10	96.26	41.85	111.12	76.49	21.56	27.98	24.77	9.14	10.05	9.60
T_7: CA + Foxtail millet	141.21	137.82	139.51	86.16	83.72	84.94	74.81	64.55	69.68	7.54	7.19	7.36
T_8: Finger millet alone	477.82	471.99	474.91	233.80	231.96	232.88	167.03	158.66	162.84	23.97	23.09	23.53
T_9: Fodder maize alone	1971.20	1782.05	1876.63	488.09	450.85	469.47	446.39	410.03	428.21	86.51	74.22	80.37
T_{10}: Field bean alone	236.49	224.50	230.50	119.47	130.63	125.05	66.42	70.20	68.31	21.21	20.91	21.06
T_{11}: Niger alone	158.61	173.36	165.99	100.41	111.61	106.01	60.01	58.54	59.28	12.98	13.68	13.33
T_{12}: Chilli alone	342.88	362.62	352.75	251.24	264.52	257.88	129.37	128.99	129.18	20.68	19.99	20.34
T_{13}: Cowpea alone	216.68	226.23	221.46	102.90	97.41	100.16	61.32	75.43	68.38	21.56	21.83	21.70
T_{14}: Foxtail millet alone	298.25	280.13	289.19	171.35	168.67	170.01	155.54	159.38	157.46	15.62	15.85	15.74
T_{15}: Custard apple alone	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
S.Em ±	**45.15**	**34.57**	**38.19**	**14.17**	**11.86**	**12.08**	**11.59**	**9.39**	**9.92**	**2.13**	**1.62**	**1.78**
CD @ 5 %	**131.25**	**100.48**	**111.01**	**41.20**	**34.48**	**35.13**	**33.69**	**27.29**	**28.84**	**6.18**	**4.72**	**5.16**

Note: CA–Custard apple

4.11.3 Total nutrient uptake by crops

Custard apple based agri–horticulture system significantly influenced the total uptake of primary, secondary and micronutrients by different crops due to variation in yield during 2017 and 2018. Generally, sole crops recorded higher nutrient uptake than their respective intercrops.

4.11.3.1 Total uptake of nitrogen, phosphorus and potassium

Custard apple based agri–horticulture system significantly influenced the total uptake of nitrogen, phosphorus and potassium among different treatments and the data are presented in Table 4.34. Generally, sole crops recorded higher total uptake of nitrogen, phosphorus and potassium than their respective intercrops. During 2017 and 2018 higher uptake was recorded in fodder maize treatments.

Pooled data revealed that significantly higher total uptake of nitrogen, phosphorus and potassium was recorded in Fodder maize alone (T_9) (123.68, 32.49 and 115.49 kg ha^{-1}, respectively) followed by T_{12} (Chilli alone) (85.23, 17.42 and 86.61 kg ha^{-1}, respectively) and T_2 (CA + Fodder maize) (81.49, 23.59 and 78.06 kg ha^{-1}, respectively) treatments. Total nitrogen uptake was found to be on par in treatments T_3 (CA + Field bean) (28.10 kg ha^{-1}), T_6 (CA + Cowpea) (23.16 kg ha^{-1}) and T_{14} (Foxtail millet alone) (26.85 kg ha^{-1}). Significantly, lower total nitrogen uptake was recorded in CA + Niger (12.29 kg ha^{-1}) followed by T_7 (CA + Foxtail millet) (13.01 kg ha^{-1}). Total uptake of phosphorus was found non–significant among T_3 (CA + Field bean) (7.14 kg ha^{-1}), T_{11} (CA + Niger) (5.47 kg ha^{-1}) and T_{14} (Foxtail millet alone) (6.46 kg ha^{-1}). Treatment T_7 (CA + Foxtail millet) (2.96 kg ha^{-1}) recorded significantly lower uptake of phosphorus. The treatments T_1 (CA + Finger millet) (27.89 kg ha^{-1}), T_3 (CA + Field bean) (28.58 kg ha^{-1}) and T_6 (CA + Cowpea) (24.10 kg ha^{-1}) were on par with each other for total potassium uptake. Significantly lower total potassium uptake was recorded under T_7 (CA + Foxtail millet) (16.43 kg ha^{-1}) followed by T_4 (CA + Niger) (21.69 kg ha^{-1}).

Table 4.34: Total nitrogen, phosphorus and potassium uptake of different crops as influenced by custard apple based agri–horticulture system during 2017 and 2018

Treatments	Nitrogen			Phosphorus			Potassium		
	(kg ha^{-1})								
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
T_1: CA + Finger millet	42.29	42.91	42.60	9.59	9.97	9.78	28.10	27.67	27.89
T_2: CA + Fodder maize	81.21	81.77	81.49	23.38	23.79	23.59	77.33	78.78	78.06
T_3: CA + Field bean	29.07	27.12	28.10	7.03	7.24	7.14	29.05	28.11	28.58
T_4: CA + Niger	11.73	12.84	12.29	3.13	3.72	3.43	21.01	22.38	21.69
T_5: CA + Chilli	49.97	67.29	58.63	10.56	13.45	12.01	51.66	65.16	58.41
T_6: CA + Cowpea	21.74	24.58	23.16	4.31	4.57	4.44	23.30	24.90	24.10
T_7: CA + Foxtail millet	12.86	13.15	13.01	2.80	3.12	2.96	16.63	16.24	16.43
T_8: Finger millet alone	79.64	79.40	79.52	18.23	15.57	16.90	54.42	52.28	53.35
T_9: Fodder maize alone	121.38	125.97	123.68	34.60	30.37	32.49	120.36	110.61	115.49
T_{10}: Field bean alone	51.20	51.31	51.26	11.92	11.32	11.62	50.71	52.14	51.42
T_{11}: Niger alone	18.27	19.64	18.96	5.34	5.59	5.47	33.03	34.99	34.01
T_{12}: Chilli alone	72.55	97.92	85.23	15.34	19.50	17.42	76.13	97.08	86.61
T_{13}: Cowpea alone	49.95	49.27	49.61	9.80	9.70	9.75	54.41	57.35	55.88
T_{14}: Foxtail millet alone	25.94	27.76	26.85	5.56	7.35	6.46	34.66	35.95	35.31
T_{15}: Custard apple alone	-----	-----	-----	-----	-----	-----	-----	-----	-----
S.Em ±	**2.80**	**3.20**	**2.73**	**0.76**	**0.75**	**0.70**	**3.59**	**3.14**	**3.19**
CD @ 5 %	**8.13**	**9.31**	**7.94**	**2.22**	**2.18**	**2.05**	**10.42**	**9.14**	**9.26**

Note: CA–Custard apple

4.11.3.2 Total uptake of calcium, magnesium and sulphur

Total uptake of calcium, magnesium and sulphur was significantly differed among the treatments under custard apple based agri–horticulture system and the data are presented in Table 4.35.

Pooled analysis of 2017 and 2018 experimental data revealed that significantly higher (45.32 kg ha^{-1}) total calcium uptake was noticed under treatment T_8 (Finger millet alone) and T_{12} (Chilli alone) (42.37 kg ha^{-1}). Total uptake of calcium was found non–significant among T_9 (Fodder maize alone) (35.12 kg ha^{-1}), T_{10} (Field bean alone) (37.74 kg ha^{-1}) and T_{13} (Cowpea alone) (36.23 kg ha^{-1}) treatments. Significantly lower (6.87 kg ha^{-1}) total calcium uptake was recorded under T_7 (CA + Foxtail millet).

Pooled data showed that higher (35.89 kg ha^{-1}) total uptake of magnesium was recorded significantly in Chilli alone (T_{12}) treatment followed by T_8 (Finger millet alone) (31.36 kg ha^{-1}). It was found non–significant among T_2 (CA + Fodder maize) (12.53 kg ha^{-1}), T_3 (CA + Field bean) (11.41 kg ha^{-1}), T_{11} (Niger alone) (12.27 kg ha^{-1}) and T_{14} (Foxtail millet alone) (10.03 kg ha^{-1}). The treatment CA + Foxtail millet (T_7) recorded significantly lower total uptake of magnesium (3.85 kg ha^{-1}) compared to other treatments.

According to pooled data, significantly higher (20.18 kg ha^{-1}) total sulphur uptake was recorded in CA + Fodder maize (T_9) treatment compared to other treatments and was followed by T_8 (Finger millet alone) (16.36 kg ha^{-1}). Total sulphur uptake was found on par among treatments T_1 (CA + Finger millet) (8.37 kg ha^{-1}), T_4 (CA + Niger) (7.51 kg ha^{-1}), T_{10} (Field bean alone) (7.60 kg ha^{-1}) and T_{13} (Cowpea alone) (8.95 kg ha^{-1}). Significantly lower total sulphur uptake was noticed under CA + Foxtail millet (T_7) (2.61 kg ha^{-1}).

4.11.3.3 Total uptake of micronutrients

Total uptake of micronutrients was significantly differed among the treatments under custard apple based agri–horticulture system during 2017 and 2018 and the data are presented in Table 4.36.

Table 4.35: Total calcium, magnesium and sulphur uptake of different crops as influenced by custard apple based agri–horticulture system during 2017 and 2018

Treatments	Calcium			Magnesium			Sulphur		
	(kg ha^{-1})								
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
T_1: CA + Finger millet	23.63	23.46	23.55	16.82	17.35	17.09	7.86	8.88	8.37
T_2: CA + Fodder maize	27.89	28.98	28.44	11.17	13.88	12.53	14.89	11.89	13.39
T_3: CA + Field bean	20.51	18.92	19.71	11.95	10.87	11.41	4.37	3.84	4.10
T_4: CA + Niger	11.39	11.93	11.66	7.61	8.08	7.84	6.94	8.08	7.51
T_5: CA + Chilli	26.07	33.63	29.85	20.87	27.19	24.03	8.50	12.37	10.44
T_6: CA + Cowpea	15.44	17.15	16.30	9.26	9.69	9.48	3.49	3.57	3.53
T_7: CA + Foxtail millet	7.07	6.67	6.87	3.84	3.86	3.85	2.55	2.66	2.61
T_8: Finger millet alone	46.11	44.53	45.32	31.83	30.89	31.36	16.02	16.69	16.36
T_9: Fodder maize alone	38.13	32.10	35.12	15.48	14.64	15.06	19.06	21.29	20.18
T_{10}: Field bean alone	37.19	38.28	37.74	21.52	21.37	21.45	7.47	7.73	7.60
T_{11}: Niger alone	17.92	18.25	18.09	11.54	13.01	12.27	10.76	11.89	11.33
T_{12}: Chilli alone	38.35	46.39	42.37	30.73	41.05	35.89	12.11	15.98	14.04
T_{13}: Cowpea alone	35.05	37.41	36.23	21.08	20.97	21.02	8.70	9.20	8.95
T_{14}: Foxtail millet alone	13.96	14.94	14.45	9.16	10.90	10.03	5.67	6.74	6.20
T_{15}: Custard apple alone	-----	-----	-----	-----	-----	-----	-----	-----	-----
S.Em ±	**1.68**	**1.55**	**1.52**	**1.13**	**1.08**	**1.04**	**0.67**	**0.60**	**0.59**
CD @ 5 %	**4.90**	**4.50**	**4.41**	**3.27**	**3.15**	**3.01**	**1.93**	**1.75**	**1.72**

Note: CA–Custard apple

Table 4.36: Total micronutrients uptake of different crops as influenced by custard apple based agri–horticulture system during 2017 and 2018

Treatments	Fe			Mn			Zn			Cu		
	(g ha^{-1})											
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
T_1: CA + Finger millet	486.09	496.00	491.05	271.26	283.52	277.39	109.35	113.53	111.44	25.47	26.33	25.90
T_2: CA + Fodder maize	1294.94	1265.61	1280.28	340.17	299.86	320.02	315.78	290.47	303.12	58.59	53.99	56.29
T_3: CA + Field bean	160.10	161.43	160.77	77.64	80.64	79.14	42.84	44.56	43.70	15.36	14.47	14.92
T_4: CA + Niger	120.74	127.90	124.32	73.26	79.60	76.43	44.99	50.85	47.92	9.46	10.31	9.88
T_5: CA + Chilli	480.95	624.99	552.97	335.75	438.79	387.27	155.99	177.42	166.70	32.06	41.23	36.65
T_6: CA + Cowpea	119.72	135.86	127.79	55.99	60.70	58.34	29.57	38.62	34.10	12.47	13.64	13.06
T_7: CA + Foxtail millet	185.96	183.77	184.87	117.05	117.90	117.48	91.15	81.38	86.26	9.70	9.46	9.58
T_8: Finger millet alone	935.61	867.23	901.42	512.82	470.17	491.50	247.70	226.78	237.24	46.63	42.85	44.74
T_9: Fodder maize alone	1971.20	1782.05	1876.63	488.09	450.85	469.47	446.39	410.03	428.21	86.51	74.22	80.37
T_{10}: Field bean alone	303.89	295.17	299.53	152.87	167.81	160.34	83.48	91.20	87.34	27.77	27.35	27.56
T_{11}: Niger alone	184.76	202.77	193.76	114.97	128.90	121.94	69.69	69.61	69.65	14.87	15.73	15.30
T_{12}: Chilli alone	724.45	928.00	826.23	507.34	670.08	588.71	227.52	296.98	262.25	46.87	59.58	53.23
T_{13}: Cowpea alone	288.46	300.72	294.59	138.06	133.92	135.99	81.65	97.93	89.79	29.01	29.41	29.21
T_{14}: Foxtail millet alone	387.34	405.99	396.67	233.00	253.48	243.24	187.85	207.03	197.44	20.08	21.38	20.73
T_{15}: Custard apple alone	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
S.Em ±	**48.64**	**39.13**	**42.04**	**19.11**	**17.57**	**17.22**	**12.53**	**10.67**	**11.04**	**2.43**	**2.01**	**2.11**
CD @ 5 %	**141.39**	**113.75**	**122.20**	**55.54**	**51.06**	**50.07**	**36.44**	**31.01**	**32.09**	**7.08**	**5.83**	**6.13**

Note: CA–Custard apple

Pooled analysis revealed that significantly higher (1876.63 g ha^{-1}) total Fe uptake was noticed in Fodder maize alone (T_9) treatment which was followed by CA + Fodder maize (T_2) (1280.28 g ha^{-1}). The treatments T_{10} (Field bean alone) (299.53 g ha^{-1}), T_{13} (Cowpea alone) (294.59 g ha^{-1}) and T_{14} (Foxtail millet alone) (396.67 g ha^{-1}) were found to be on par with each other. Significantly lower (124.32 g ha^{-1}) total Fe uptake was recorded in CA + Niger (T_4) treatment but it was non–significant with T_6 (CA + Cowpea) (127.79 g ha^{-1}), T_7 (CA + Foxtail millet) (184.87 g ha^{-1}), T_{11} (Niger alone) (193.76 g ha^{-1}) and T_3 (CA + Field bean) (160.77 g ha^{-1}).

Pooled data showed that Chilli alone (T_{12}) recorded significantly higher (588.71 g ha^{-1}) total Mn uptake compared to other treatments. Total Mn uptake was found non–significant among the treatments T_{13} (Cowpea alone) (135.99 g ha^{-1}), T_{11} (Niger alone) (121.94 g ha^{-1}), T_{10} (Field bean alone) (160.34 g ha^{-1}) and T_7 (CA + Foxtail millet) (117.48 g ha^{-1}). Significantly lower (58.34 g ha^{-1}) total Mn uptake was noticed under CA + Cowpea (T_6) treatment however, this was on par with T_4 (CA + Niger) (76.43 g ha^{-1}) and T_3 (CA + Field bean) (79.14 g ha^{-1}).

According to pooled analysis significantly higher (428.21 g ha^{-1}) total Zn uptake was noticed in treatment Fodder maize alone (T_9) compared to other treatments. Total Zn uptake was non–significant among the treatments T_7 (CA + Foxtail millet) (86.26 g ha^{-1}), T_{10} (Field bean alone) (87.34 g ha^{-1}), T_{11} (Niger alone) (69.65 g ha^{-1}) and T_{13} (Cowpea alone) (89.79 g ha^{-1}). Treatment CA + Cowpea (T_6) recorded significantly lower (34.10 g ha^{-1}) total Zn uptake compared to other treatments except T_4 (CA + Niger) (47.92 g ha^{-1}) and T_3 (CA + Field bean) (43.70 g ha^{-1}) where it was non–significant.

Pooled analysis revealed that total uptake of Cu was found significantly higher (80.37 g ha^{-1}) under Fodder maize alone (T_9) treatment compared to other treatments. However, the total uptake of Cu was found non–significant among T_3 (CA + Field bean) (14.92 g ha^{-1}), T_6 (CA + Cowpea) (13.06 g ha^{-1}) and T_{11} (Niger alone) (15.30 g ha^{-1}). Treatment T_7 (CA + Foxtail millet) recorded significantly lower (9.58 g ha^{-1}) total Cu uptake compared to other treatments except T_4 (CA + Niger) (9.88 g ha^{-1}) where it was found non–significant.

The variation in micronutrients accumulation could be due to availability and uptake of these nutrients by the plants and variations in growth and biomass production. Higher concentration of micronutrients was probably due to greater availability and uptake of ions (Singh *et al.,* 2002). The variation in nutrient uptake among different crops might be due variation in biomass production and nutrient uptake potential.

4.12 Effect of custard apple based agri–horticulture system on soil chemical properties after harvest of crops during 2017 and 2018

4.12.1 Soil pH, electrical conductivity and organic carbon content of soil

The data pertaining to soil pH, electrical conductivity (EC) and organic carbon content is presented in Table 4.37. Custard apple based agri–horticulture system significantly influenced the organic carbon content of soil but the effect on soil pH and EC was non–significant after harvest of the crops during 2017 and 2018 as well as in pooled data. However, in pooled data the soil pH was ranged from 5.27 in CA + Field bean (T_3) to 5.43 in CA + Finger millet (T_1) whereas, EC was ranged from 0.04 dS m^{-1} in CA + Finger millet to 0.06 dS m^{-1} in Custard apple alone treatments.

The custard apple based agri–horticulture system significantly influenced the organic carbon content of soil after harvest of the crops during 2017 and 2018. Significantly higher organic carbon content was recorded in CA + Cowpea (T_6) (6.56 and 6.57 g kg^{-1}) treatment which was on par with CA + Field bean (T_3) (6.48 and 6.49 g kg^{-1}), Cowpea alone (T_{13}) (6.32 and 6.35 g kg^{-1}) and Field bean alone (T_{10}) (6.20 and 6.22 g kg^{-1}) during 2017 and 2018, respectively. Significantly lower organic carbon content was found in treatments Fodder maize alone (4.85 and 4.85 g kg^{-1}) and CA + Fodder maize (5.10 and 5.11 g kg^{-1}) during 2017 and 2018, respectively.

Pooled analysis of 2017 and 2018 experimental data showed that significantly higher organic carbon was maintained under treatment CA + Cowpea (T_6) (6.57 g kg^{-1}) followed by CA + Field bean (T_3) (6.49 g kg^{-1}), Cowpea alone (T_{13}) (6.34 g kg^{-1}) and Field bean alone (T_{10}) (6.21 g kg^{-1}).

Table 4.37: Soil pH, electrical conductivity (EC) and organic carbon content of soil as influenced by custard apple based agri–horticulture system after harvest of crops during 2017 and 2018

Treatments	Soil pH			EC (dS m^{-1})			Organic carbon (g kg^{-1})		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1: CA + Finger millet	5.44	5.41	5.43	0.04	0.05	0.04	5.77	5.79	5.78
T_2: CA + Fodder maize	5.31	5.30	5.31	0.04	0.04	0.04	5.10	5.11	5.11
T_3: CA + Field bean	5.28	5.25	5.27	0.04	0.05	0.05	6.48	6.49	6.49
T_4: CA + Niger	5.42	5.43	5.43	0.04	0.04	0.04	5.49	5.51	5.50
T_5: CA + Chilli	5.44	5.43	5.43	0.05	0.05	0.05	5.58	5.60	5.59
T_6: CA + Cowpea	5.30	5.29	5.29	0.04	0.05	0.04	6.56	6.57	6.57
T_7: CA + Foxtail millet	5.43	5.42	5.43	0.04	0.04	0.04	5.36	5.38	5.37
T_8: Finger millet alone	5.39	5.36	5.38	0.05	0.04	0.05	5.57	5.56	5.57
T_9: Fodder maize alone	5.34	5.36	5.35	0.05	0.05	0.05	4.85	4.85	4.85
T_{10}: Field bean alone	5.28	5.28	5.28	0.05	0.05	0.05	6.20	6.22	6.21
T_{11}: Niger alone	5.38	5.37	5.38	0.05	0.04	0.04	5.16	5.18	5.17
T_{12}: Chilli alone	5.36	5.38	5.37	0.05	0.05	0.05	5.42	5.45	5.44
T_{13}: Cowpea alone	5.29	5.30	5.30	0.04	0.04	0.04	6.32	6.35	6.34
T_{14}: Foxtail millet alone	5.39	5.36	5.38	0.04	0.05	0.05	5.19	5.18	5.19
T_{15}: Custard apple alone	5.40	5.44	5.42	0.06	0.05	0.06	5.16	5.19	5.18
S.Em ±	**0.21**	**0.26**	**0.16**	**0.01**	**0.01**	**0.01**	**0.27**	**0.27**	**0.27**
CD @ 5 %	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**0.78**	**0.78**	**0.78**

Note: CA–Custard apple
NS–Non significant

However, the organic carbon was non–significant among T_4 (CA + Niger) (5.50 g kg^{-1}), T_5 (CA + Chilli) (5.59 g kg^{-1}), T_7 (CA + Foxtail millet) (5.37 g kg^{-1}), T_8 (Finger millet alone) (5.57 g kg^{-1}) and T_{12} (Chilli alone) (5.44 g kg^{-1}). Significantly lower organic carbon was found in treatment T_9 (Fodder maize alone) (4.85 g kg^{-1}). Irrespective of the crops, organic carbon was found higher under intercropping systems compared to their respective sole crops but the difference was non–significant. Higher organic carbon under custard apple based intercropping systems might be due to the increased addition of crop residues from both main crop as well as intercrop, better soil and moisture conservation. Similar conclusions were reported by Das *et al.* (2011) and Ramulu, (2014). Irrespective of the treatments, the organic carbon content of soil was increased after harvest of crops compared to the organic carbon status of soil before sowing during 2017 and 2018. Increase in organic carbon content might be attributed to increased quantity of plant residue addition through higher root biomass and litterfall both from custard apple and agriculture crops and reduced soil disturbance. Similar results also reported by Liao and Boutton (2008).

4.12.2 Available nitrogen, phosphorus and potassium in soil

4.12.2.1 Available N

Custard apple based agri–horticulture system significantly influenced available nitrogen in soil after harvest of the crops during 2017 and 2018 and the values are presented in Table 4.38.

After harvest of the crops available N was found significantly higher in treatment CA + Cowpea (T_6) (105.31 and 106.48 mg kg^{-1}) followed by CA + Field bean (T_3) (104.70 and 106.43 mg kg^{-1}), Cowpea alone (T_{13}) (98.87 and 100.55 mg kg^{-1}) and Field bean alone (T_{10}) (98.30 and 98.83 mg kg^{-1}) during 2017 and 2018, respectively. The treatment Fodder maize alone (T_9) (54.10 and 58.96 mg kg^{-1}) recorded significantly lower available N in soil followed by T_2 (CA + Fodder maize) (62.12 and 63.33 mg kg^{-1}) during 2017 and 2018, respectively.

Pooled data of 2017 and 2018 revealed that, CA + Cowpea (T_6) (105.90 mg kg^{-1}) treatment maintained significantly higher available N in soil. However, this was on par with T_3 (CA + Field bean) (105.57 mg kg^{-1}) and T_{13} (Cowpea alone) (99.71 mg kg^{-1}). This could be attributed to addition of nitrogen to soil through symbiotic nitrogen fixation and addition of organic matter in the form of leaf litter with higher leaf N concentration by the legume crops. Similar results were obtained by Das *et al*. (2011), Lal *et al*. (2011) and Avinash Chandra Rathore *et al*. (2013). Fodder maize alone (T_9) recorded significantly lower available N (56.53 mg kg^{-1}) due to lower organic matter content in soil as well higher nitrogen removal by crop due to higher biomass production as well as non -addition of crop residue back to soil. Whereas, the treatments T_1 (CA + Finger millet) (80.28 mg kg^{-1}), T_4 (CA + Niger) (81.29 mg kg^{-1}), T_5 (CA + Chilli) (79.60 mg kg^{-1}), T_7 (CA + Foxtail millet) (77.84 mg kg^{-1}), T_8 (Finger millet alone) (71.44 mg kg^{-1}) and T_{14} (Foxtail millet alone) (72.85 mg kg^{-1}) were found to be on par with each other. Irrespective of the treatments, the available N content of soil was decreased after harvest of crops compared to the available N status of soil before sowing during 2017 and 2018 which might be due to nitrogen removal by crop, losses due to leaching and volatilization. The present results are in accordance with Sharma *et al.* (2009).

4.12.2.2 Available P_2O_5

The available P_2O_5 content of soil after harvest of crops during 2017 and 2018 was differed significantly among treatments under custard apple based agri–horticulture system and the data are presented in Table 4.38.

During 2017 and 2018, significantly higher available P_2O_5 was found in treatment CA + Cowpea (T_6) (30.90 and 31.44 mg kg^{-1}, respectively). This was on par with CA + Field bean (T_3) (28.68 and 29.80 mg kg^{-1}), Cowpea alone (T_{13}) (25.56 and 25.33 mg kg^{-1}) and Field bean alone (T_{10}) (26.15 and 25.35 mg kg^{-1}) during 2017 and 2018, respectively. Significantly lower available P_2O_5 in soil was recorded in the treatment Fodder maize alone (T_9) (13.72 and 12.68 mg kg^{-1}) followed by T_2 (CA + Fodder maize) (15.89 and 15.41 mg kg^{-1}) during 2017 and 2018, respectively.

Pooled analysis of 2017 and 2018 data showed that, after harvest of crops CA + Cowpea (T_6) (31.17 mg kg^{-1}) treatment maintained significantly higher available P_2O_5 in soil. But, this was on par with T_3 (CA + Field bean) (29.24 mg kg^{-1}), T_{13} (Cowpea alone) (25.45 mg kg^{-1}) and T_{10} (Field bean alone) (25.75 mg kg^{-1}). Higher available P_2O_5 in treatments with legume crops compared to other treatments after harvest might be due to higher organic matter content and enzyme activity in soil which might be responsible for mobilization of P in soil from unavailable P pools. These results are in accordance with Nuruzzaman *et al.* (2005) who reported that the carboxylate–exuding legumes, such as field pea, exude particularly large amounts of organic acids into the rhizosphere, especially as a response to P–deficiency. Under such conditions, these exudates can help mobilise P from soil–P pools. The increase in P may also be due to release of organically bound P during decomposition of organic matter, solubilization of soil P by organic acids produced during decomposition of organic matter. Fodder maize alone (T_9) recorded significantly lower available P_2O_5 (13.20 mg kg^{-1}) followed by T_2 (CA + Fodder maize) (15.65 mg kg^{-1}) due to lower organic matter content in soil as well higher removal by crop due to higher biomass production. However, the treatments T_1 (CA + Finger millet) (21.55 mg kg^{-1}), T_4 (CA + Niger) (21.80 mg kg^{-1}), T_7 (CA + Foxtail millet) (23.95 mg kg^{-1}) and T_{14} (20.04 mg kg^{-1}) were found to be on par with each other. It was also observed that available P_2O_5 was found higher under intercropping systems than sole crops of respective crops but the difference was non–significant. In agroforestry and agri–horticultural systems, the greater P content could be due to crop residue addition as well as recycling of P through mining by the tree species and subsequently recycling by way of surface litter fall (Sharma *et al.,* 2009). The increase in available phosphorus under tree–based land use systems and forest cover have been reported earlier by Kumar and Chaudhuri (1997). At harvest of the crops during 2017 and 2018, available P_2O_5 in soil decreased which might be due to crop removal, physico–chemical immobilization of P (adsorption, precipitation *etc.)* into insoluble forms or due to microbial immobilization. These results are in conformity with Math and Halikatti (2012) and Avinash Chandra Rathore *et al.* (2013)

4.12.2.3 Available K_2O

The data on available K_2O content of soil after harvest of crops during 2017 and 2018 as influenced by custard apple based agri–horticulture system is presented in Table 4.38. Custard apple based agri–horticulture system significantly influenced available K_2O content in soil during 2017 and 2018 as well as pooled data. CA + Cowpea (T_6) had significantly higher available K_2O (70.28 and 72.64 mg kg^{-1}) followed by T_3 (CA + Field bean) (70.65 and 72.06 mg kg^{-1}) and T_{13} (Cowpea alone) (63.68 and 64.44 mg kg^{-1}) during 2017 and 2018, respectively. Fodder maize alone (T_9) recorded significantly lower available K_2O (43.15 and 41.40 mg kg^{-1}) during 2017 and 2018, respectively. However, this was on par with T_2 (CA + Fodder maize) (46.89 and 48.31 mg kg^{-1} during 2017 and 2018, respectively).

Pooled analysis of data revealed that, after harvest of crops available K_2O was maintained higher in treatment CA + Cowpea (T_6) (71.46 mg kg^{-1}) which was on par with T_3 (CA + Field bean) (71.36 mg kg^{-1}), T_{13} (Cowpea alone) (64.06 mg kg^{-1}) and T_{10} (Field alone) (63.66 mg kg^{-1}). Higher amount of potassium content in the soil under these treatments might be due to increase in SOC content of soil after decomposition of biomass of intercrops that builds up total population of beneficial microbes in the soil. The increment in soil microbial population might have helped to release higher amount of soil K from organically fixed potassium. Similar results of improvement in nutrient status of soil due to intercropping have been reported by Gupta and Sharma (2009). Available K_2O was found non–significant among treatments T_1 (CA + Finger millet) (62.70 mg kg^{-1}), T_4 (CA + Niger) (57.62 mg kg^{-1}), T_5 (CA + Chilli) (54.13 mg kg^{-1}), T_7 (CA + Foxtail millet) (60.83 mg kg^{-1}) and T_{14} (57.07 mg kg^{-1}). Fodder maize alone (T_9) recorded significantly lower available K_2O (42.27 mg kg^{-1}) followed by T_2 (CA + Fodder maize) (47.60 mg kg^{-1}). Lower amount of available K_2O in fodder maize treatments might be due to leaching loss, potassium fixation, crop uptake as fodder maize is an exhaustive crop both under sole and intercropping which decreased the available K_2O status. It was also observed that after harvest of crops intercropping systems contained higher available K_2O than sole crops of respective crops but the difference was non–significant.

Table 4.38: Available N, P_2O_5 and K_2O content of soil as influenced by custard apple based agri–horticulture system after harvest of crops during 2017 and 2018

Treatments	Available N			Available P_2O_5			Available K_2O		
	(mg kg^{-1})								
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
T_1: CA + Finger millet	79.57	80.99	80.28	21.07	22.02	21.55	61.64	63.77	62.70
T_2: CA + Fodder maize	62.12	63.33	62.73	15.89	15.41	15.65	46.89	48.31	47.60
T_3: CA + Field bean	104.70	106.43	105.57	28.68	29.80	29.24	70.65	72.06	71.36
T_4: CA + Niger	80.80	81.78	81.29	21.62	21.97	21.80	57.90	57.33	57.62
T_5: CA + Chilli	80.28	78.91	79.60	18.41	18.08	18.25	53.63	54.63	54.13
T_6: CA + Cowpea	105.31	106.48	105.90	30.90	31.44	31.17	70.28	72.64	71.46
T_7: CA + Foxtail millet	77.44	78.23	77.84	23.56	24.34	23.95	59.92	61.73	60.83
T_8: Finger millet alone	71.78	71.10	71.44	17.00	17.93	17.46	52.70	52.11	52.41
T_9: Fodder maize alone	54.10	58.96	56.53	13.72	12.68	13.20	43.15	41.40	42.27
T_{10}: Field bean alone	98.30	98.83	98.57	26.15	25.35	25.75	64.48	62.84	63.66
T_{11}: Niger alone	77.14	78.24	77.69	15.39	15.71	15.55	50.04	50.64	50.34
T_{12}: Chilli alone	68.79	69.97	69.38	17.19	18.09	17.64	54.63	53.91	54.27
T_{13}: Cowpea alone	98.87	100.55	99.71	25.56	25.33	25.45	63.68	64.44	64.06
T_{14}: Foxtail millet alone	73.19	72.51	72.85	20.36	19.73	20.04	56.35	57.78	57.07
T_{15}: Custard apple alone	82.72	79.75	81.23	21.87	22.44	22.16	53.55	55.75	54.65
S.Em ±	**3.68**	**4.72**	**4.12**	**1.33**	**1.22**	**1.20**	**2.63**	**3.40**	**2.93**
CD @ 5 %	**10.67**	**13.68**	**11.92**	**3.85**	**3.53**	**3.47**	**7.62**	**9.86**	**8.49**

Note: CA–Custard apple

Higher availability of K at surface layers under legume based intercropping systems attributed to liberation of organically bound K from decomposition of litter fall as well as solubilization of insoluble forms of K present in soil due to organic decomposition products. Most of the potassium is lying free in the plant cell and does not become part of any cell component and is easily released upon decomposition (Shehnaz Sharma *et al.,* 2015). Decrease in the available potassium content of soil after harvest of the crops during 2017 and 2018 might be due to the crop removal, leaching loss and K fixation (Kumar *et al.,* 2011).

4.12.3 Exchangeable calcium, magnesium and available sulphur

There was a significant difference among the treatments with respect to exchangeable calcium, magnesium and available sulphur after harvest of crops during 2017 and 2018 under custard apple based agri–horticulture system and the data is presented in Table 4.39. Significantly higher exchangeable Ca (2.53 and 2.59 cmol (p^+) kg^{-1}), Mg (1.25 and 1.31 cmol (p^+) kg^{-1}) and available S (15.41 and 15.88 mg kg^{-1}) was maintained under CA + Cowpea (T_6) during 2017 and 2018, respectively followed by T_3 (CA + Field bean). Significantly lower exchangeable Ca (1.56 and 1.48 cmol (p^+) kg^{-1}), Mg (0.56 and 0.60 cmol (p^+) kg^{-1}) and available S (7.35 and 7.56 mg kg^{-1}) was recorded under Fodder maize alone (T_9) during 2017 and 2018, respectively which was on par with CA + Fodder maize.

Pooled data showed that significantly higher exchangeable Ca (2.56 cmol (p^+) kg^{-1}), Mg (1.28 cmol (p^+) kg^{-1}) and available S (15.65 mg kg^{-1}) was recorded under CA + Cowpea (T_6) followed by T_3 (CA + Field bean) (2.44–Ca, 1.23–Mg cmol (p^+) kg^{-1} and 15.60–S mg kg^{-1}, respectively). The higher exchangeable Ca, Mg and available S content in soil under custard apple intercropped with legumes might be due to crop residues addition through litter fall and higher root biomass both from trees and legume crops and it was available after decomposition and mineralization. Similar results were reported by Sharma *et al.* (2009) and Hemalatha and Chellamuthu (2013). Fodder maize alone (T_9) significantly recorded lower exchangeable Ca (1.52 cmol (p^+) kg^{-1}), Mg (0.58 cmol (p^+) kg^{-1}) and available S (7.45 mg kg^{-1}).

Table 4.39: Exchangeable Ca, Mg and Available S content of soil as influenced by custard apple based agri–horticulture system after harvest of crops during 2017 and 2018

Treatments	Exchangeable Ca			Exchangeable Mg			Available S		
	(cmol (p+) kg^{-1})						(mg kg^{-1})		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1: CA + Finger millet	2.03	2.16	2.10	1.20	1.17	1.18	11.91	12.08	11.99
T_2: CA + Fodder maize	1.63	1.56	1.60	0.62	0.53	0.58	8.23	7.68	7.95
T_3: CA + Field bean	2.37	2.51	2.44	1.21	1.24	1.23	14.85	16.34	15.60
T_4: CA + Niger	1.82	1.83	1.83	1.01	1.08	1.05	12.62	12.87	12.75
T_5: CA + Chilli	1.87	1.91	1.89	0.95	1.02	0.98	11.24	13.24	12.24
T_6: CA + Cowpea	2.53	2.59	2.56	1.25	1.31	1.28	15.41	15.88	15.65
T_7: CA + Foxtail millet	2.06	1.96	2.01	0.98	0.96	0.97	12.16	12.45	12.31
T_8: Finger millet alone	1.71	1.83	1.77	1.09	1.05	1.07	9.98	10.25	10.12
T_9: Fodder maize alone	1.56	1.48	1.52	0.56	0.60	0.58	7.35	7.56	7.45
T_{10}: Field bean alone	2.24	2.28	2.26	1.16	1.18	1.17	16.27	15.24	15.75
T_{11}: Niger alone	2.07	2.12	2.10	0.87	0.84	0.86	12.43	11.35	11.89
T_{12}: Chilli alone	1.75	1.73	1.74	0.71	0.68	0.70	11.85	12.09	11.97
T_{13}: Cowpea alone	2.29	2.35	2.32	1.18	1.21	1.20	16.44	17.39	16.92
T_{14}: Foxtail millet alone	1.67	1.66	1.66	0.86	0.85	0.86	13.02	14.42	13.72
T_{15}: Custard apple alone	1.95	1.83	1.89	0.71	0.73	0.72	12.90	13.15	13.03
S.Em ±	**0.09**	**0.11**	**0.10**	**0.05**	**0.05**	**0.05**	**0.60**	**0.63**	**0.62**
CD @ 5 %	**0.27**	**0.31**	**0.29**	**0.14**	**0.15**	**0.14**	**1.75**	**1.82**	**1.78**

Note: CA–Custard apple

This might be due to exhaustive nature of fodder maize which resulted in higher biomass production and higher nutrient uptake. Similar results were obtained by Lal *et al*. (2011) and Avinash Chandra Rathore *et al*. (2013). It was also observed that intercropping systems maintained higher exchangeable calcium, magnesium and available sulphur in soil after harvest of crops than sole crops of respective crops but the difference was non–significant. After harvest of the crops, there was significant decrease in the exchangeable Ca, Mg and available S compared to before sowing during 2017 and 2018. It might be attributed to crop removal and leaching losses.

4.12.4 Micronutrient content

Custard apple based agri–horticulture system significantly influenced the micronutrient content in soil after harvest of the crops during 2017 and 2018 and the data are presented in Table 4.40. The DTPA–extractable micronutrients declined from their respective initial values as a result of continuous cropping and uptake. Significantly higher Fe (12.31 and 12.28 mg kg^{-1}), Mn (34.05 and 34.02 mg kg^{-1}), Zn (2.20 and 2.21 mg kg^{-1}) and Cu (1.14 and 1.11 mg kg^{-1}) was noticed in treatment CA + Cowpea (T_6) during 2017 and 2018, respectively which was followed by CA + Field bean (T_3), Cowpea alone (T_{13}) and Field bean alone (T_{10}). Significantly lower Fe (5.26 and 5.43 mg kg^{-1}), Mn (20.35 and 20.07 mg kg^{-1}), Zn (0.98 and 1.01 mg kg^{-1}) and Cu (0.51 and 0.52 mg kg^{-1}) was recorded in Fodder maize alone (T_9) during 2017 and 2018, respectively.

Pooled data revealed that, after harvest of crops significantly higher Fe, Mn, Zn and Cu were found in treatment CA + Cowpea (T_6) (12.30, 34.04, 2.21 and 1.13 mg kg^{-1}, respectively) and this was followed by T_3 (CA + Field bean) (12.15, 33.10, 2.20 and 1.09 mg kg^{-1}, respectively). It was also observed that comparatively intercropping systems recorded higher micronutrients than sole crops of respective crops after harvest of crops but the difference was non–significant. Under intercropping systems especially with legume crops increased micronutrient content in soil might be due to increased biomass of crops, thereby leaving more root biomass in the soil for mineralization. Higher root mass in soil and subsequent decomposition might have influenced the organic carbon status of the soil along with DTPA extractable micronutrients content in soil.

Table 4.40: Micronutrients content of soil as influenced by custard apple based agri–horticulture system after harvest of crops during 2017 and 2018

Treatments	Fe			Mn			Zn			Cu		
	(mg kg^{-1})											
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
T_1: CA + Finger millet	9.12	10.35	9.74	29.51	30.04	29.78	1.27	1.29	1.28	0.87	0.85	0.86
T_2: CA + Fodder maize	6.03	6.14	6.09	22.43	21.36	21.90	1.04	1.03	1.04	0.58	0.57	0.57
T_3: CA + Field bean	12.06	12.24	12.15	32.46	33.73	33.10	2.18	2.21	2.20	1.10	1.08	1.09
T_4: CA + Niger	12.04	12.09	12.07	33.68	32.39	33.03	2.12	2.14	2.13	1.06	1.03	1.05
T_5: CA + Chilli	8.34	8.41	8.38	30.09	28.61	29.35	1.18	1.15	1.17	0.81	0.78	0.80
T_6: CA + Cowpea	12.31	12.28	12.30	34.05	34.02	34.04	2.20	2.21	2.21	1.14	1.11	1.13
T_7: CA + Foxtail millet	9.87	9.83	9.85	32.17	32.27	32.22	2.08	2.06	2.07	1.04	1.03	1.04
T_8: Finger millet alone	7.98	8.64	8.31	27.63	27.78	27.71	1.15	1.17	1.16	0.73	0.75	0.74
T_9: Fodder maize alone	5.26	5.43	5.35	20.35	20.07	20.21	0.98	1.01	1.00	0.51	0.52	0.52
T_{10}: Field bean alone	11.51	11.59	11.55	33.74	33.21	33.48	2.13	2.15	2.14	1.03	1.06	1.05
T_{11}: Niger alone	11.86	10.98	11.42	32.69	32.74	32.72	2.08	2.08	2.08	0.98	0.99	0.99
T_{12}: Chilli alone	8.36	8.36	8.36	27.09	26.73	26.91	1.17	1.14	1.15	0.72	0.72	0.72
T_{13}: Cowpea alone	12.09	12.03	12.06	33.20	33.23	33.22	2.18	2.14	2.16	1.03	1.05	1.04
T_{14}: Foxtail millet alone	11.58	11.62	11.60	30.79	30.86	30.83	1.98	2.00	1.99	1.02	1.02	1.02
T_{15}: Custard apple alone	8.31	8.33	8.32	26.44	26.47	26.46	1.67	1.67	1.67	0.88	0.89	0.89
S.Em ±	**0.52**	**0.47**	**0.49**	**1.52**	**1.41**	**1.46**	**0.08**	**0.08**	**0.08**	**0.05**	**0.04**	**0.05**
CD @ 5 %	**1.50**	**1.37**	**1.42**	**4.40**	**4.09**	**4.23**	**0.24**	**0.24**	**0.24**	**0.14**	**0.13**	**0.13**

Note: CA–Custard apple

Swarup (1984) reported that the incorporation of organic manures brought about a remarkable improvement in the availability of native and micronutrient cation in soil form stable complexes with organic ligands that decrease their susceptibility to adsorption, fixation or precipitation in the soil. The addition of organic manures might have resulted in the formation of such metal organic complexes of higher availability (Gupta *et al*., 2000).

Fodder maize alone (T_9) recorded significantly lower Fe (5.35 mg kg^{-1}), Mn (20.21 mg kg^{-1}), Zn (1.00 mg kg^{-1}) and Cu (0.52 mg kg^{-1}) cntents in soil followed by T_2 (CA + Fodder maize). Decreased micronutrient content in soil under fodder maize might be due to higher uptake by crop due to higher biomass production resulted in higher crop uptake as well as non–return of crop residue to soil. Similar results were obtained by Lal *et al*. (2011) and Avinash Chandra Rathore *et al.* (2013). This was in accordance with the continuous uptake by the crops over the years in addition to their non–replenishment (Sanjib Kumar *et al.*, 2009). The difference in various micronutrients status under different treatments might be attributed to variation in concentration, uptake by different crops, varying rates of their release through decomposition of organic residues and rate of decomposition of these nutrients in litterfall as well as the quantity of litterfall added (Shehnaz Sharma *et al.*, 2015). Generally, the nutrient status of soil after harvest of the crops was lesser during both years due to removal of nutrients by the crops. Significantly low nutrient status in soil under fodder maize treatment was due to removal of more amount of nutrients by the fodder maize (Ramulu, 2014).

4.13 Effect of custard apple based agri–horticulture system on soil biological properties after harvest of crops during 2017 and 2018

4.13.1 Dehydrogenase activity

Soil enzymes are the primary mediators of soil biological processes, including organic matter degradation, mineralization and nutrient cycling (Li *et al.,* 2009). Soil microorganisms degrade organic matter through the production of different extracellular enzymes and for this reason after the application of green manures to soil, the enzymatic activity of the soil increases (Tejada *et al.,* 2008). Custard apple based agri–horticulture

system significantly influenced the dehydrogenase activity in soil after harvest of crops during 2017 and 2018 and the data are presented in Table 4.41. During 2017 and 2018 significantly higher dehydrogenase activity was noticed in treatment CA + Cowpea (T_6) (44.63 and 46.86 µg TPF g^{-1} of soil day^{-1}, respectively) followed by T_3 (CA + Field bean) (42.34 and 45.07 µg TPF g^{-1} of soil day^{-1}, respectively) and T_{13} (Cowpea alone) (39.04 and 41.87 µg TPF g^{-1} of soil day^{-1}, respectively). Among the treatments, significantly lower dehydrogenase activity (20.89 and 21.73 µg TPF g^{-1} of soil day^{-1}, respectively) was recorded in Fodder maize alone (T_9) during 2017 and 2018 which was on par with T_2 (CA + Fodder maize) (22.61 and 22.80 µg TPF g^{-1} of soil day^{-1}, respectively).

Pooled analysis of 2017 and 2018 experimental data showed that, among the treatments significantly higher dehydrogenase activity (45.75 µg TPF g^{-1} of soil day^{-1}) was maintained in treatment CA + Cowpea (T_6). However, this was on par with treatments T_3 (CA + Field bean) (43.71 µg TPF g^{-1} of soil day^{-1}). Significantly higher dehydrogenase activity maintained in treatments with legume crops might be due to the fact that leguminous crops with lower C:N ratio, contain easily available compounds, such as amino acids and carbohydrates, which can stimulate the microbial population and increase the dehydrogenase activity. These results are in conformity with Kumar and Goh (2003) and Dinesh *et al.* (2004). These findings also corroborate the findings of Rai and Yadav (2011) who reported maximum activity of dehydrogenase in the rhizosphere of legumes. Dehydrogenase activity was found non–significant among the treatments T_1 (CA + Finger millet) (32.46 µg TPF g^{-1} of soil day^{-1}), T_4 (CA + Niger) (28.95 µg TPF g^{-1} of soil day^{-1}), T_5 (CA + Chilli) (30.20 µg TPF g^{-1} of soil day^{-1}), T_7 (CA + Foxtail millet) (30.03 µg TPF g^{-1} of soil day^{-1}) and T_8 (Finger millet alone) (29.53 µg TPF g^{-1} of soil day^{-1}). Significantly lower dehydrogenase activity (21.31 µg TPF g^{-1} of soil day^{-1}) was recorded in treatment Fodder maize alone (T_9) but it was on par with T_{15} (Custard apple alone) (21.65 µg TPF g^{-1} of soil day^{-1}) and T_2 (CA + Fodder field) (22.71 µg TPF g^{-1} of soil day^{-1}). These fluctuations in dehydrogenase activity could be due to variations in soil moisture and temperature, crop species and available substrate. Small shifts in the structure of the microbial community can result in large chances in biomass nitrogen.

Table 4.41: Dehydrogenase, urease and phosphatase activity in soil as influenced by custard apple based agri–horticulture system after harvest of crops during 2017 and 2018

Treatments	Dehydrogenase			Urease			Acid Phosphatase			Alkaline Phosphatase		
	(µg TPF g^{-1} of soil day^{-1})			(µg NH_4-N g^{-1} dry soil hr^{-1})			(µg PNP g^{-1} of dry soil hr^{-1})					
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1: CA + Finger millet	31.03	33.89	32.46	4.69	4.97	4.83	17.62	18.68	18.15	7.44	8.55	8.00
T_2: CA + Fodder maize	22.61	22.80	22.71	3.76	3.66	3.71	14.31	14.17	14.24	5.38	5.89	5.64
T_3: CA + Field bean	42.34	45.07	43.71	5.32	5.56	5.44	22.45	25.78	24.12	10.68	11.36	11.02
T_4: CA + Niger	28.52	29.38	28.95	4.86	4.84	4.85	17.06	16.88	16.97	6.87	7.03	6.95
T_5: CA + Chilli	29.28	31.11	30.20	4.76	4.87	4.82	16.81	18.14	17.48	6.32	8.07	7.20
T_6: CA + Cowpea	44.63	46.86	45.75	5.51	5.60	5.56	22.91	26.06	24.49	11.21	13.77	12.49
T_7: CA + Foxtail millet	30.18	29.88	30.03	4.21	4.26	4.24	17.36	18.01	17.69	8.03	8.27	8.15
T_8: Finger millet alone	28.67	30.38	29.53	4.36	4.41	4.39	16.03	15.75	15.89	7.11	8.54	7.83
T_9: Fodder maize alone	20.89	21.73	21.31	3.37	3.40	3.39	14.28	12.15	13.21	5.21	4.60	4.91
T_{10}: Field bean alone	37.22	41.99	39.61	5.11	5.20	5.16	20.06	21.86	20.96	9.67	10.97	10.32
T_{11}: Niger alone	26.62	28.48	27.55	4.23	4.30	4.27	16.43	18.58	17.51	6.13	5.36	5.75
T_{12}: Chilli alone	27.81	27.31	27.56	4.48	4.54	4.51	17.12	16.58	16.85	5.98	5.84	5.91
T_{13}: Cowpea alone	39.04	41.87	40.46	5.26	5.30	5.28	21.41	21.77	21.59	10.23	11.42	10.83
T_{14}: Foxtail millet alone	26.47	26.41	26.44	4.18	4.21	4.20	17.01	18.33	17.67	6.54	5.78	6.16
T_{15}: Custard apple alone	21.22	22.07	21.65	3.68	3.83	3.76	14.28	15.85	15.07	5.24	5.15	5.20
S.Em ±	**1.83**	**1.70**	**1.71**	**0.25**	**0.22**	**0.23**	**1.09**	**0.90**	**0.97**	**0.36**	**0.39**	**0.38**
CD @ 5 %	**5.29**	**4.92**	**4.94**	**0.74**	**0.64**	**0.68**	**3.15**	**2.60**	**2.81**	**1.05**	**1.14**	**1.09**

Note: CA–Custard apple

4.13.2 Urease activity

Urease activity varied significantly under custard apple based agri–horticulture system after harvest of crops during 2017 and 2018 and the data are presented in Table 4.41. Among the treatments, significantly higher (5.51 and 5.60 µg NH_4–N g^{-1} of soil hr^{-1}) urease activity was found in treatment CA + Cowpea (T_6) during 2017 and 2018, respectively. However, this was found on par with T_3 (CA + Field bean) (5.32 and 5.56 µg NH_4–N g^{-1} of soil hr^{-1}). Fodder maize alone (T_9) maintained significantly lower (3.37 and 3.40 µg NH_4–N g^{-1} of soil hr^{-1}) urease activity during 2017 and 2018, respectively and this was on par with T_{15} (Custard apple alone) (3.68 and 3.83 µg NH_4–N g^{-1} of soil hr^{-1}) and T_2 (CA + Fodder maize) (3.76 and 3.66 µg NH_4–N g^{-1} of soil hr^{-1}).

Results of the pooled analysis revealed that, CA + Cowpea (T_6) maintained significantly higher (5.56 µg NH_4–N g^{-1} of soil hr^{-1}) urease activity after harvest of crops which was on par with T_3 (CA + Field bean) (5.44 µg NH_4–N g^{-1} of soil hr^{-1}). Higher urease activity in these treatments may be attributed to increasing population of microorganisms like bacteria etc., due to increased availability of substrate through organic matter releasing these enzymes of extra cellular origin. Similar findings were reported by Singaram and Kamala Kumari (2000). It was found non–significant among T_1 (CA + Finger millet) (4.83 µg NH_4–N g^{-1} of soil hr^{-1}), T_4 (CA + Niger) (4.85 µg NH_4–N g^{-1} of soil hr^{-1}), T_5 (CA + Chilli) (4.82 µg NH_4–N g^{-1} of soil hr^{-1}), T_8 (Finger millet alone) (4.39 µg NH_4–N g^{-1} of soil hr^{-1}), T_{12} (Chilli alone) (4.51 µg NH_4–N g^{-1} of soil hr^{-1}) and T_{14} (Foxtail millet alone) (4.20 µg NH_4–N g^{-1} of soil hr^{-1}). Fodder maize alone (T_9) recorded significantly lower (3.39 µg NH_4–N g^{-1} of soil hr^{-1}) urease activity followed by CA + Fodder maize (T_2) (3.71 µg NH_4–N g^{-1} of soil hr^{-1}) and T_{15} (Custard apple alone) (3.76 µg NH_4–N g^{-1} of soil hr^{-1}). Enhanced and variation in soil urease activity under custard apple based intercropping systems compared to sole cropping could be attributed to regular addition and decomposition of litter under custard apple. Similar results were reported by Yadav *et al.* (2008).

4.13.3 Acid and alkaline phosphatase activity

Acid and alkaline phosphatase activity after harvest of crops varied significantly under custard apple based agri–horticulture system among different crops during 2017 and 2018 and the data are presented in Table 4.41. Significantly higher acid (22.91 and 26.06 µg PNP g^{-1} of soil hr^{-1}) and alkaline (11.21 and 13.77 µg PNP g^{-1} of soil hr^{-1}) phosphatase activity was noticed in treatment CA + Cowpea (T_6) during 2017 and 2018, respectively. Significantly lower acid (14.28 and 12.15 µg PNP g^{-1} of soil hr^{-1}) and alkaline (5.21 and 4.60 µg PNP g^{-1} of soil hr^{-1}) phosphatase activity was noticed in Fodder maize alone (T_9) during 2017 and 2018, respectively.

Pooled analysis of 2017 and 2018 experimental data showed that, CA + Cowpea (T_6) recorded significantly higher acid (24.49 µg PNP g^{-1} of soil hr^{-1}) and alkaline (12.49 µg PNP g^{-1} of soil hr^{-1}) phosphatase activity followed by T_3 (CA + Field bean) (24.12 and 11.02 µg PNP g^{-1} of soil hr^{-1} acid and alkaline phosphatase activity, respectively. Significantly higher acid and alkaline phosphatase activity in treatments with legume crops might be due to greater plant–derived phosphatase with growth of custard apple with additional production of acid phosphatase with legumes by free root nodule bacteria, during the initiation of symbiosis. Increased phosphatase activity might also be due increased organic matter content of soil which might have improved the microbial activity. These results are in conformity with George *et al.* (2002). It may also be directly related to the input of plant litter as well as the rhizospheric effect of legume crops. George *et al.* (2002) reported an increase in the phosphatase activity in soil, either directly by secretion from the rhizosphere or indirectly by the stimulation of microbial activity. Also, the highest content of soil organic matter found in agroforestry system had positive influence on enzymes activity, such as acid phosphatase. The acid and alkaline phosphatase activity was found non–significant among T_1 (CA + Finger millet) (18.15 and 8.00 µg PNP g^{-1} of soil hr^{-1}, respectively), T_5 (CA + Chilli) (17.48 and 7.20 µg PNP g^{-1} of soil hr^{-1}, respectively), T_7 (CA + Foxtail millet) (17.69 and 8.15 µg PNP g^{-1} of soil hr^{-1}, respectively) and T_8 (Finger millet alone) (15.89 and 7.83 µg PNP g^{-1} of soil hr^{-1}, respectively). Significantly lower acid (13.21 µg PNP g^{-1} of soil hr^{-1}) and alkaline (4.91 µg PNP g^{-1} of soil hr^{-1}) phosphatase activity was recorded in treatment Fodder maize

alone (T_9). Significantly lower acid and alkaline phosphatase activity in fodder maize might be due to low soil organic carbon. It was also observed that with respect to specific crops acid and alkaline phosphatase activity was higher under intercrops than sole crops. Intercropping enhances soil acid phosphatase activity compared to monocropping, suggesting that intercropping may utilize more soil organic P which, however, depends on crop combination and P fertilization (Zhi-Gang Wang *et al.,* 2014). Some reports showed that chickpea and peanut have been identified as species whose roots exudate large amounts of acid phosphatase into their rhizosphere (Li *et al.,* 2004; Gunes *et al.,* 2007).

4.13.4 Microbial biomass carbon

The microbial biomass and enzyme activity are the main biological indicators of soil quality and respond rapidly to changes resulting from agronomic practices (Araujo *et al.*, 2003). Microbial biomass C significantly varied among the treatments under custard apple based agri–horticulture system during 2017 and 2018 after harvest of the crops and the data are presented in Table 4.42. During 2017 and 2018, significantly higher (293.17 and 295.83 mg kg^{-1}, respectively) microbial biomass C was noticed in treatment CA + Cowpea (T_6) and this was followed by T_3 (CA + Field bean) (285.13 and 289.58 mg kg^{-1}, respectively). Significantly lower (201.49 and 213.55 mg kg^{-1}, respectively) microbial biomass C was recorded under Fodder maize alone (T_9) during 2017 and 2018. However, this was on par with T_{15} (Custard apple alone) (210.57 and 214.99 mg kg^{-1}, respectively) and T_2 (CA + Fodder maize) (215.64 and 218.39 mg kg^{-1}, respectively) during 2017 and 2018.

Pooled analysis showed that CA + Cowpea (T_6) maintained significantly higher (294.50 mg kg^{-1}) microbial biomass C. However, this was on par with treatments T_3 (CA + Field bean) (287.36 mg kg^{-1}), T_{13} (Cowpea alone) (286.73 mg kg^{-1}) and T_{10} (Field bean alone) (276.99 mg kg^{-1}). The highest values of microbial biomass of C found in the these treatments may be influenced by higher plant diversity and litter fall and addition of large crop residues from legumes. This finding indicates that the higher content of different plant litter, which supplies diverse C sources (Lopes *et al.,* 2010; Campos *et al.,* 2014).

Francisco *et al.* (2016) found that the higher MBC values were found in soils under agroforestry system. The microbial biomass C was found non–significant among the treatments T_1 (CA + Finger millet) (233.69 mg kg^{-1}), T_4 (CA + Niger) (228.94 mg kg^{-1}), T_7 (CA + Foxtail millet) (227.61 mg kg^{-1}), T_8 (Finger millet alone) (229.69 mg kg^{-1}) T_{14} (Foxtail millet alone) (216.30 mg kg^{-1}) T_{11} (Niger alone) (221.86 mg kg^{-1}). Significantly lower (207.52 mg kg^{-1}) microbial biomass C was recorded in treatment Fodder maize alone (T_9) which was followed by T_{15} (Custard apple alone) (212.78 mg kg^{-1}), T_{14} (Foxtail millet alone) (216.30 mg kg^{-1}) and T_2 (CA + Fodder maize) (217.02 mg kg^{-1}). Significantly lower microbial biomass C in fodder maize might be due to decreased organic carbon and removal crop residues. It was also observed that with respect to specific crops microbial biomass C was higher under intercrops than sole crops. This could be attributed to regular addition and decomposition of litter and crop residue under custard apple. Similar results were reported by Yadav *et al.* (2008).

4.13.5 Microbial biomass nitrogen

Under custard apple based agri–horticulture system microbial biomass N significantly varied among the treatments after harvest of the crops during 2017 and 2018 and the data are presented in Table 4.42. Significantly higher (34.20 and 34.51 mg kg^{-1}) microbial biomass N was recorded in treatment CA + Cowpea (T_6) which was followed by T_3 (CA + Field bean) (33.27 and 33.78 mg kg^{-1}) during 2017 and 2018, respectively. Significantly lower (23.51 and 24.91 mg kg^{-1}, respectively) microbial biomass N was noticed under Fodder maize alone (T_9) during 2017 and 2018. However, this was on par with T_2 (CA + Fodder maize) (25.16 and 25.48 mg kg^{-1}, respectively) during 2017 and 2018.

Pooled analysis of 2017 and 2018 experimental data revealed that CA + Cowpea (T_6) maintained significantly higher (34.36 mg kg^{-1}) microbial biomass N. However, this was on par with treatments T_3 (CA + Field bean) (33.53 mg kg^{-1}), T_{13} (Cowpea alone) (33.45 mg kg^{-1}) and T_{10} (Field bean alone) (32.32 mg kg^{-1}). It is evident that readily metabolizable carbon and N in FYM in addition to increasing root biomass and root exudates due to greater crop growth were the most influential factors contributing to the

increase in soil microbial biomass N. The microbial biomass N was found on par among the treatments T_4 (CA + Niger) (26.71 mg kg^{-1}), T_7 (CA + Foxtail millet) (26.56 mg kg^{-1}), T_8 (Finger millet alone) (26.80 mg kg^{-1}) and T_{11} (Niger alone) (25.89 mg kg^{-1}). Significantly lower (24.21 mg kg^{-1}) microbial biomass N was recorded in treatment Fodder maize alone (T_9) which was followed by T_{15} (Custard apple alone) (24.83 mg kg^{-1}) and T_2 (CA + Fodder maize) (25.32 mg kg^{-1}). Significantly lower ac microbial biomass N in fodder maize might be due to low organic carbon and decreased microbial carbon. It was also observed that with respect to specific crops microbial biomass N was higher under intercrops than sole crops related to increase in the soil organic matter under intercropping systems and the reduced rate of leaching in the soil profile. Higher soil microbial N was mainly contributed by the decomposition of leaf litter, root and crop residues (Ramulu *et al.*, 2017). Yadav *et al.* (2008) reported the increase in soil microbial N under multipurpose tree-based agroforestry system due to regular addition and decomposition of litter under agroforestry.

4.13.6 Microbial biomass phosphorus

Custard apple based agri–horticulture system significantly influenced the microbial biomass P content in soil and it varied significantly among the treatments after harvest of the crops during 2017 and 2018 and the data are presented in Table 4.42. Microbial biomass P was recorded significantly higher (2.98 and 3.13 mg kg^{-1}) in treatment CA + Cowpea (T_6) which was followed by T_3 (CA + Field bean) (2.78 and 2.85 mg kg^{-1}) during 2017 and 2018, respectively. Significantly lower (1.26 and 1.31 mg kg^{-1}, respectively) microbial biomass P was noticed under Fodder maize alone (T_9) during 2017 and 2018. However, this was followed by T_{15} (Custard apple alone) (1.34 and 1.42 mg kg^{-1}, respectively) and T_2 (CA + Fodder maize) (1.32 and 1.41 mg kg^{-1}, respectively) during 2017 and 2018.

Pooled data revealed that CA + Cowpea (T_6) maintained significantly higher (3.06 mg kg^{-1}) microbial biomass P. However, this was on par with treatments T_3 (CA + Field bean) (2.82 mg kg^{-1}) and T_{13} (Cowpea alone) (2.66 mg kg^{-1}). In the present study, more microbial biomass P under legume treatments might be due to more affiliation and

Table 4.42: Microbial biomass carbon (C), nitrogen (N) and phosphorus (P) in soil as influenced by custard apple based agri–horticulture system after harvest of crops during 2017 and 2018

Treatments	Microbial Biomass C			Microbial Biomass N			Microbial Biomass P		
	(mg kg^{-1})								
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1: CA + Finger millet	231.25	236.13	233.69	26.98	27.55	27.26	2.02	2.14	2.08
T_2: CA + Fodder maize	215.64	218.39	217.02	25.16	25.48	25.32	1.32	1.41	1.37
T_3: CA + Field bean	285.13	289.58	287.36	33.27	33.78	33.53	2.78	2.85	2.82
T_4: CA + Niger	227.49	230.39	228.94	26.54	26.88	26.71	1.87	1.85	1.86
T_5: CA + Chilli	251.48	250.42	250.95	29.34	29.22	29.28	1.98	2.06	2.02
T_6: CA + Cowpea	293.17	295.83	294.50	34.20	34.51	34.36	2.98	3.13	3.06
T_7: CA + Foxtail millet	224.86	230.36	227.61	26.23	26.88	26.56	1.75	1.81	1.78
T_8: Finger millet alone	228.32	231.05	229.69	26.64	26.96	26.80	1.86	1.82	1.84
T_9: Fodder maize alone	201.49	213.55	207.52	23.51	24.91	24.21	1.26	1.31	1.28
T_{10}: Field bean alone	273.18	280.79	276.99	31.87	32.76	32.32	2.50	2.65	2.58
T_{11}: Niger alone	220.64	223.08	221.86	25.74	26.03	25.89	1.79	1.84	1.82
T_{12}: Chilli alone	239.34	241.80	240.57	27.92	28.21	28.07	1.83	1.90	1.87
T_{13}: Cowpea alone	284.49	288.96	286.73	33.19	33.71	33.45	2.63	2.68	2.66
T_{14}: Foxtail millet alone	216.63	215.96	216.30	25.27	25.20	25.23	1.72	1.75	1.74
T_{15}: Custard apple alone	210.57	214.99	212.78	24.57	25.08	24.83	1.34	1.42	1.38
S.Em ±	**11.56**	**12.41**	**11.94**	**1.35**	**1.45**	**1.39**	**0.11**	**0.10**	**0.10**
CD @ 5 %	**33.50**	**35.94**	**34.59**	**3.91**	**4.19**	**4.04**	**0.33**	**0.29**	**0.30**

Note: CA–Custard apple

interaction of P-phosphate solubilizing microorganisms with cowpea and field bean crops, which resulted in more soil microbial biomass P contents. Similar results were reported by Ullah *et al.* (2013) in case of mungbean. The microbial biomass P was non–significant among the treatments T_1 (CA + Finger millet) (2.30 mg kg^{-1}), T_5 (CA + Chilli) (2.02 mg kg^{-1}) and T_8 (Finger millet alone) (1.84 mg kg^{-1}). Significantly lower (1.28 mg kg^{-1}) microbial biomass P was recorded in treatment Fodder maize alone (T_9) which was followed by T_{15} (Custard apple alone) (1.38 mg kg^{-1}) and T_2 (CA + Fodder maize) (1.37 mg kg^{-1}).

4.14 Correlation coefficient among different soil properties after harvest of the crops at 0–15 cm depth of soil

Simple correlation coefficient among soil organic carbon with other soil properties after harvest of the crops is presented in Table 4.43. It was observed that the soil organic carbon shown significantly positive correlation with all the soil properties except bulk density and pH. Among the physical properties, aggregate stability ($r=0.944^{**}$), MWD ($r=0.899^{**}$), MWHC ($r=0.897^{**}$) and infiltration rate ($r=0.900^{**}$) had significantly positive correlation with soil organic carbon but the bulk density ($r=-0.832^{**}$) had significantly negative correlation with soil organic carbon.

The significantly positive correlation between MWD and SOC indicated that formation of stable aggregates is highly influenced by SOC, there by influencing better water holding capacity and infiltration rate (Benbi and Senapati, 2010). Humic acid and inorganics play important role in stabilization of clay microstructure (<2 µm diameter), whereas micro– and macroaggregates are stabilized by bacteria, fungi, microbial derived substances, plant roots and their exudates, which are directly and/or indirectly influenced by amount of organic matter present in the soil (Aparicio and Costa, 2007). Ibrahim Ortas and Rattan Lal (2012) found that there is a negative and significant correlation between MWD and soil bulk density and a positive correlation between MWD and total porosity. Hatti *et al.* (2008) reported that the SOC content at 0 to 30 cm soil depth showed a highly significant and positive linear relationship with mean weight diameter and total porosity and a highly significant negative linear relationship with bulk density of the soil.

Table 4.43: Correlation matrix (r–value) among different soil properties at 0–15 cm depth after harvest of the crops

Parameters	SOC	CEC	BD	AG.S	MWD	MWHC	IR	pH	AV.N	AV.P_2O_5	AV.K_2O	DHA	UA	ACID.P	ALK.P	MBC	MBN	MBP
SOC	1.000																	
CEC	0.940**	1.000																
BD	-0.832**	-0.831**	1.000															
AG.S	0.944**	0.936**	-0.914**	1.000														
MWD	0.899**	0.884**	-0.731**	0.910**	1.000													
MWHC	0.897**	0.892**	-0.807**	0.865**	0.724**	1.000												
IR	0.900**	0.913**	-0.802**	0.854**	0.718**	0.862**	1.000											
pH	-0.588*	-0.525*	0.506	-0.512	-0.294	-0.756**	-0.638*	1.000										
AV.N	0.929**	0.842**	-0.714**	0.900**	0.927**	0.763**	0.779**	-0.497	1.000									
AV.P_2O_5	0.868**	0.833**	-0.618*	0.842**	0.893**	0.726**	0.772**	-0.421	0.926**	1.000								
AV.K_2O	0.901**	0.879**	-0.735**	0.905**	0.939**	0.749**	0.798**	-0.373	0.917**	0.963**	1.000							
DHA	0.980**	0.951**	-0.896**	0.973**	0.887**	0.910**	0.924**	-0.597*	0.920**	0.860**	0.901**	1.000						
UA	0.943**	0.858**	-0.889**	0.944**	0.894**	0.772**	0.815**	-0.396	0.887**	0.796**	0.879**	0.940**	1.000					
ACID.P	0.940**	0.885**	-0.859**	0.952**	0.892**	0.861**	0.855**	-0.574*	0.943**	0.890**	0.931**	0.971**	0.916**	1.000				
ALK.P	0.967**	0.970**	-0.837**	0.949**	0.873**	0.909**	0.931**	-0.590*	0.899**	0.881**	0.891**	0.980**	0.889**	0.930**	1.000			
MBC	0.969**	0.876**	-0.850**	0.911**	0.814**	0.910**	0.861**	-0.660**	0.899**	0.806**	0.825**	0.961**	0.913**	0.927**	0.936**	1.000		
MBN	0.971**	0.872**	-0.853**	0.929**	0.804**	0.898**	0.849**	-0.663**	0.904**	0.826**	0.824**	0.972**	0.919**	0.908**	0.941**	1.979**	1.000	
MBP	0.976**	0.917**	-0.899**	0.968**	0.888**	0.904**	0.887**	-0.586*	0.923**	0.841**	0.890**	0.992**	0.956**	0.975**	0.956**	0.968**	0.968**	1.000

Note: * and ** indicate significance values at P=0.05 and 0.01 level, respectively. SOC–Soil organic carbon, CEC–Cation exchange capacity, BD–Bulk density, AG.S–Aggregate stability, MWD–Mean weight diameter, MWHC–Maximum water holding capacity, IR–Infiltration rate, AV.N–Available N, AV.P_2O_5–Available P, AV.K_2O–Available K, DHA–Dehydrogenase, UA– Urease, ACID.P– Acid phosphatase, ALK.P–Alkaline phosphatase, MBC–Microbial biomass carbon, MBN–Microbial biomass nitrogen and MBP–Microbial biomass phosphorus.

Significantly negative correlation between bulk density and organic carbon indicated that increase in organic matter content in soil decreased soil bulk density. Strong negative correlation was also reported by Bindu Sharma and Sujata Bhattacharya (2017) and Hema Singh *et al*. (2011). Jiao *et al.* (2009) also indicated that SOC content were negatively related to bulk density. It is known that the organic matter density is usually lower than that of mineral soil. This reduces the average bulk density of a mixture as organic matter increases (dilution effect) (Papini *et al.,* 2011). The organic matter itself enhances soil resistance to compaction through several mechanisms (strengthening of binding forces among particles and aggregates and higher elasticity of aggregates under compression) and promotes a higher porosity, thus keeping soil bulk density lower (Soane, 1990).

Soil pH had significantly negative correlation with soil organic carbon ($r=-0.588^{*}$). This may be attributed to faster rate of decomposition and production of organic acids which decreases the soil pH. The soil pH had negative correlation with available nutrients like nitrogen (r=-0.497), phosphorus (r=-0.421) and potassium (r=-0.373). The significantly negative correlation between soil pH and available nitrogen indicated that increase in soil pH decreased available nitrogen, which might be due to volatilization loss of nitrogen with rise in soil pH. The negatively significant relationship between soil pH and available phosphorus may be due to conversion of soluble phosphorus to insoluble calcium and magnesium phosphate thus reducing its availability with the rise in soil pH. Similar results were reported Patil *et al.* (2015).

Available nutrients like nitrogen ($r=0.929^{**}$), phosphorus ($r=0.868^{**}$) and potassium ($r=0.901^{**}$) maintained significantly positive correlation with soil organic carbon. The significant and positive correlation between soil organic carbon and available nitrogen in soil could be because release of mineralizable nitrogen from soil organic matter in soil and adsorption of NH_4–N by humus complexes in soil. These results are in accordance with Kumar *et al.* (2014). The significantly positive correlation between soil organic carbon and available phosphorus in soil might be due to acidifying effect of organic carbon, formation of easily accessible organophosphate complexes, release of phosphorus from organic complexes and reduction in phosphorus fixation by humus due

to formation of coatings on iron and aluminum oxides (Ayele *et al.,* 2013). The significantly positive correlation between soil organic carbon and available potassium in soil might be due to release of potassium after mineralization of organic matter as well as release of potassium from soil mineral resources. The soil available nutrients were positively correlated with soil properties like water holding capacity and aggregate stability, negatively correlated with bulk density. As the organic matter decomposes, it colours the soil darker; increases soil aggregation and aggregate stability; increases the CEC and contributes to nutrient pool (Bot and Benites, 2005).

Soil organic carbon was maintained significantly positively correlated with soil microbial properties like dehydrogenase activity ($r=0.980^{**}$), urease activity ($r=0.943^{**}$), acid phosphatase ($r=0.940^{**}$), alkaline phosphatase ($r=0.967^{**}$), MBC ($r=0.969^{**}$), MBN ($r=0.971^{**}$) and MBP ($r=0.976^{**}$). Microbial biomass C was significantly positively correlated with dehydrogenase activity ($r=0.961^{**}$), urease activity ($r=0.913^{**}$), acid phosphatase ($r=0.927^{**}$), alkaline phosphatase ($r=0.936^{**}$), MBN ($r=0.979^{**}$) and MBP ($r=0.968^{**}$), suggesting that these are primarily of microbial origin. Generally, the enzyme activities in the soil were closely related to the organic matter content. Improved organic matter, substrate availability and microbial biomass carbon status of soil resulted in higher enzyme activity (Asit Mandal *et al.,* 2007). This reflects the greater biological activity in soil and the stabilization of extracellular enzymes through complexation with humic substances (Basak *et al.,* 2013). Generally, enzyme activities of soils are usually correlated with their organic carbon and available N contents (Taylor *et al.,* 2002).

Microbial biomass C showed significantly positive correlation available nutrients like nitrogen ($r=0.899^{**}$), phosphorus ($r=0.806^{**}$) and potassium ($r=0.825^{**}$). It was reported that the increase in dehydrogenase activity and microbial biomass in soil were proportional to the addition of number and amount of nutrients to soil (Manjaiah and Singh, 2001).

4.15 Conclusion

Cropping systems are important practices which influence soil fertility and productivity in any agriculture system. Different cropping systems have different capacity to add carbon to soil thereby contributing towards soil fertility. Soil carbon is the one important factor on which soil fertility depends. Soil nitrogen is an essential element which makes up major portion of plant dry matter. Agri–horticulture system is an important approach especially under dryland situations. This system enables the producer to use all the resources efficiently including better soil and water conservation. Results of the present study revealed that the legume–based cropping systems help in maintaining better soil fertility and productivity of the soil. All carbon and nitrogen fractions (Except SIC) estimated in this experiment were found higher under legume crops intercropped with custard apple as well as in sole legume crops compared to other crops suggesting the importance of legume crops for soil fertility. The contents of carbon and nitrogen fractions were decreased with increase in soil depth except soil inorganic carbon. This suggests that these fractions are mainly influenced by the management practices like cropping systems, organic matter addition to soil, cultivation practices, fertilizer application *etc.,* which often occur on the surface soil. There was wide variation in the soil physico–chemical and biological properties due to different crops and intercropping systems revealing the effect of different crops on soil. The present investigation also revealed the variation in yield of one system compared to another system suggesting no two systems are same. Under dryland conditions adoption of proper cropping systems especially tree–based systems are more effective in terms of productivity and sustainability.

4.16 Practical utility of the research

Based on the results obtained in the present study, the following points of practical significance in custard apple based agri–horticulture system are presented.

- Legume crops intercropped with custard apple resulted in improved soil physico–chemical and biological properties thereby contributing to the soil fertility. These

crops also enhanced the contents of carbon and nitrogen fractions in soil at different depths.

- The carbon and nitrogen fractions showed significant positive correlation among each other suggesting that they are interdependent except soil inorganic carbon which was negatively correlated.
- Soil organic carbon had positive correlation with other soil properties except bulk density. The bulk density had significantly negative correlation with soil organic carbon suggesting the importance of organic matter in reducing bulk density and improving soil physical conditions.

4.17 Future line of work

- A comprehensive model need based on long term study to be developed to evaluate the long term effect of custard apple based agri–horticulture system on soil fertility including carbon and nitrogen dynamics.
- Further research is needed to study the dynamics of other nutrients under custard apple based agri–horticulture system
- Sustainability of custard apple based agri–horticulture system needs to be evaluated at different agro-climatic zones of Karnataka.
- Conservation agriculture practices with different intercrops in custard apple based agri–horticulture system to be evaluated.
- Crop intensification with double cropping approach for bimodal rainfall distribution in arid apple based agri–horticulture system need to be assessed.

V SUMMARY

Soil organic matter (SOM) or soil organic carbon (SOC) is considered as a key attribute of soil fertility and productivity because of its importance in maintaining soil's physical, chemical as well as biological properties. As soil organic matter is a heterogeneous mixture of organic substances, the different forms or fractions of SOC might have different effects on soil fertility and quality. Soil nitrogen is an essential element which makes up major portion of plant dry matter. Soil nitrogen is yet another important attribute which influence the crop production and as an essential element which makes up major portion of plant dry matter. The carbon and nitrogen accumulation in soil as well as soil fertility varies widely depending on the management practices adopted and the level of conservation measures taken in any agriculture practice. Under dryland conditions maintaining the higher carbon and nitrogen level in soil is very difficult due to sparse vegetation and lack of water. Under these conditions concept of agri–horticulture becomes important which not only helps in maintaining soil fertility, soil and water conservation but also helps in increasing the crop productivity there by contributing to the higher farm income.

Considering these aspects, a field study was undertaken entitled "**Carbon and nitrogen dynamics under agri-horticulture system**" during *Kharif* seasons of 2017 and 2018 at AICRP for Dryland Agriculture, GKVK, University of Agricultural Sciences, Bangalore. The purpose of investigation was (i) to study the carbon and nitrogen dynamics under agri–horticulture systems, (ii) to assess the soil physical, chemical and biological properties under agri–horticulture systems and (iii) to assess the productivity of land under diversified cropping systems. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. The results obtained under this experiment are summarized and presented in this chapter.

Salient findings of the present investigation are summarized as follows

Physical properties under custard apple based agri–horticulture system

- ✓ In the present experiment the content of sand, silt and clay did not vary significantly among the treatments and textural class was found to be sandy clay loam. But the texture was ranged from 62.48% to 57.37% sand, 14.62% to 12.41% silt and 28.74% to 24.22% clay.
- ✓ Significantly lower bulk density (1.38 g cm^{-3}) was recorded in CA + cowpea (T_6) at 0–15 cm depth of soil followed by CA + field bean (T_3) (1.38 g cm^{-3}) and Cowpea alone (T_{13}) (1.40 g cm^{-3}). Significantly higher bulk density was maintained under Fodder maize alone (1.50 g cm^{-3}).
- ✓ Higher aggregate stability and MWD (64.51% and 1.93 mm, respectively) were noticed in CA + Cowpea (T_6) followed by Cowpea alone (T_{13}) (63.73% and 1.87 mm, respectively) and T_3 (CA + Field bean) (63.32% and 1.91 mm, respectively). Significantly lower aggregate stability and MWD (49.36% and 1.50 mm, respectively) were noticed in T_9 (Fodder maize alone).
- ✓ Among the different treatments, CA + Cowpea (T_6) recorded significantly higher maximum water holding capacity (41.53%) followed by Cowpea alone (T_{13}) (40.26%), CA + Field bean (T_3) (39.66%) and Field bean alone (T_{10}) (39.17%). Significantly lower MWHC was noticed in custard apple alone (T_{15}) (33.19%) followed by CA + Fodder maize (T_2) (34.31%) and Fodder maize alone (T_9) (35.29%).
- ✓ Infiltration rate of soil was found to be significantly higher in CA + Cowpea (T_6) (24.99 cm hr^{-1}). This was followed by CA + Field bean (T_3) (24.37 cm hr^{-1}), Cowpea alone (T_{13}) (20.67 cm hr^{-1}) and Field bean alone (T_{10}) (20.81 cm hr^{-1}). Significantly lower infiltration rate was recorded in T_{15} (Custard apple alone) (12.36 cm hr^{-1}).

Soil chemical and biological properties before sowing of the crops under custard apple based agri–horticulture system

- ✓ During 2017 and 2018 soil pH and EC was non–significant among different treatments. However, in pooled data the soil pH was ranged from 5.42 in CA + Cowpea (T_6) to 5.53 in CA + Foxtail millet (T_7) whereas, EC (dS m^{-1}) was ranged from 0.04 in CA + Fodder maize to 0.06 in Custard apple alone treatments.
- ✓ Significantly higher organic carbon content of soil was recorded in CA + Cowpea (T_6) (6.54 and 6.54 g kg^{-1}) followed by CA + Field bean (T_3) (6.44 and 6.46 g kg^{-1}) during 2017 and 2018, respectively. Organic carbon content was found significantly lower in Fodder maize alone (4.83 and 4.83 g kg^{-1}) and CA + Fodder maize (5.05 and 5.06 g kg^{-1}) during 2017 and 2018, respectively.
- ✓ Significantly higher CEC was recorded under CA + Cowpea (T_6) (6.61 cmol (p^+) kg^{-1}) followed by CA + Field bean (T_3) (6.58 cmol (p^+) kg^{-1}). Significantly lower CEC was found in T_9 (Fodder maize alone) (5.38 cmol (p^+) kg^{-1}) followed by T_{15} (Custard apple alone) (5.40 cmol (p^+) kg^{-1}).
- ✓ Irrespective of the treatments, the available N was low in soil during 2017 and 2018. Available N was found significantly higher in CA + Cowpea (T_6) (117.19 and 117.97 mg kg^{-1}) followed by CA + Field bean (T_3) (115.60 and 117.60 mg kg^{-1}), Cowpea alone (T_{13}) (108.95 and 109.53 mg kg^{-1}) and Field bean alone (T_{10}) (109.97 and 109.25 mg kg^{-1}) during 2017 and 2018, respectively. Fodder maize alone (T_9) (74.69 and 75.56 mg kg^{-1}) recorded significantly lower available N in soil followed by T_2 (CA + Fodder maize) (76.86 and 80.87 mg kg^{-1}) during 2017 and 2018, respectively.
- ✓ During 2017 and 2018, significantly higher available P_2O_5 was found in CA + Cowpea (T_6) (36.12 and 35.82 mg kg^{-1}, respectively). This was followed by CA + Field bean (T_3) (35.12 and 36.35 mg kg^{-1}, respectively). Significantly lower available P_2O_5 in soil was recorded in the Fodder maize alone (T_9) (22.69 and 21.75 mg kg^{-1}) during 2017 and 2018, respectively.
- ✓ Significantly higher available K_2O (78.67 and 79.21 mg kg^{-1}) was noticed in CA + Cowpea (T_6) followed by T_3 (CA + Field bean) (76.51 and 78.46 mg kg^{-1}) and T_{13}

(Cowpea alone) (75.10 and 73.31 mg kg^{-1}) during 2017 and 2018, respectively. Fodder maize alone (T_9) recorded significantly lower available K_2O (52.05 and 50.17 mg kg^{-1}) during 2017 and 2018, respectively.

- ✓ Significantly higher exchangeable Ca (3.36 and 3.43 cmol (p^+) kg^{-1}), Mg (2.14 and 2.15 cmol (p^+) kg^{-1}) and available S (19.77 and 19.44 mg kg^{-1}) was recorded under CA + Cowpea (T_6) during 2017 and 2018, respectively followed by T_3 (CA + Field bean). Significantly lower exchangeable Ca (2.71 and 2.67 cmol (p^+) kg^{-1}), Mg (1.43 and 1.49 cmol (p^+) kg^{-1}) and available S (12.30 and 13.31 mg kg^{-1}) was recorded under fodder maize alone during 2017 and 2018, respectively.
- ✓ Significantly higher Fe (16.28 and 15.89 mg kg^{-1}), Mn (41.60 and 40.74 mg kg^{-1}), Zn (3.31 and 3.32 mg kg^{-1}) and Cu (1.43 and 1.42 mg kg^{-1}) was noticed in CA + Cowpea (T_6) during 2017 and 2018, respectively which was followed by CA + Field bean (T_3). Significantly lower Fe (7.24 and 7.09 mg kg^{-1}), Mn (26.60 and 24.87 mg kg^{-1}), Zn (2.66 and 2.65 mg kg^{-1}) and Cu (0.69 and 0.68 mg kg^{-1}) was recorded in Fodder maize alone (T_9) during 2017 and 2018, respectively.
- ✓ During 2017 and 2018 significantly higher dehydrogenase activity was noticed in CA + Cowpea (T_6) (57.64 and 60.52 µg TPF g^{-1} of soil day^{-1}, respectively) followed by T_3 (CA + Field bean) (54.32 and 58.69 µg TPF g^{-1} of soil day^{-1}, respectively). Significantly lower dehydrogenase activity (35.66 and 37.09 µg TPF g^{-1} of soil day^{-1}, respectively) was recorded in Fodder maize alone (T_9) during 2017 and 2018.
- ✓ Among the treatments, significantly higher (7.98 and 8.38 µg NH_4–N g^{-1} of soil hr^{-1}) urease activity was found in CA + Cowpea (T_6) during 2017 and 2018, respectively. Fodder maize alone (T_9) recorded significantly lower (4.27 and 4.44 µg NH_4–N g^{-1} of soil hr^{-1}) urease activity during 2017 and 2018, respectively.
- ✓ Significantly higher acid (27.81 and 30.20 µg PNP g^{-1} of soil hr^{-1}) and alkaline (16.68 and 18.51 µg PNP g^{-1} of soil hr^{-1}) phosphatase activity during 2017 and 2018, respectively were recorded under CA + Cowpea (T_6). Significantly lower acid (18.90 and 19.66 µg PNP g^{-1} of soil hr^{-1}) and alkaline (10.08 and 10.48 µg PNP g^{-1} of soil hr^{-1}) phosphatase activity was noticed in Fodder maize alone (T_9) during 2017 and 2018, respectively.

- ✓ During 2017 and 2018, significantly higher (322.42 and 330.54 mg kg^{-1}, respectively) microbial biomass C was noticed in CA + Cowpea (T_6) and this was followed by T_3 (CA + Field bean) (314.91 and 325.46 mg kg^{-1}, respectively). Significantly lower (228.43 and 227.57 mg kg^{-1}, respectively) microbial biomass C was recorded under Fodder maize alone (T_9) during 2017 and 2018.
- ✓ Significantly higher (37.62 and 38.56 mg kg^{-1}) microbial biomass N was recorded in CA + Cowpea (T_6) which was followed by T_3 (CA + Field bean) (36.74 and 37.97 mg kg^{-1}) during 2017 and 2018, respectively. Significantly lower (26.65 and 26.55 mg kg^{-1}, respectively) microbial biomass N was noticed under Fodder maize alone (T_9) during 2017 and 2018.
- ✓ Microbial biomass P was recorded significantly higher (3.63 and 3.71 mg kg^{-1}) in CA + Cowpea (T_6) which was followed by T_3 (CA + Field bean) (3.47 and 3.62 mg kg^{-1}) during 2017 and 2018, respectively. Significantly lower (1.56 and 1.62 mg kg^{-1}, respectively) microbial biomass P was noticed under Fodder maize alone (T_9) during 2017 and 2018.

Carbon and nitrogen dynamics under custard apple based agri–horticulture system

- ✓ At 0–15 cm soil depth, significantly higher organic carbon in soil was recorded under CA + Cowpea (6.56 and 6.57 g kg^{-1}) (T_6) followed by CA + Field bean (6.48 and 6.49 g kg^{-1}) (T_3) during 2017 and 2018, respectively. Significantly lower organic carbon content of soil during 2017 and 2018 was observed in fodder maize alone (4.85 and 4.85 g kg^{-1}, respectively) (T_9). Similar trend was observed at 15–30, 30–60 and 60–90 cm depth of soil. At all depths CA + Cowpea (T_6) had significantly higher organic carbon.
- ✓ Significantly higher inorganic carbon content of soil at 0–15 cm depth was observed in Fodder maize alone (0.92 and 0.95 g kg^{-1}) (T_9) which was followed by Custard apple alone (0.90 and 0.93 g kg^{-1}) (T_{15}) during 2017 and 2018, respectively. Significantly lower inorganic carbon in soil both during 2017 and 2018 recorded in Cowpea alone (0.62 and 0.60 g kg^{-1}, respectively) (T_{13}) followed by CA + Cowpea (0.63 and 0.62 g kg^{-1}, respectively). At all other depths higher inorganic carbon

content was recorded by Fodder maize alone (T_9) but at 30–60 and 60–90 cm depth it was non–significant.

- ✓ Significantly higher (293.17 and 295.83 mg kg^{-1}) soil microbial carbon at 0–15 cm depth of soil was recorded in T_6 (CA + Cowpea) followed by T_3 (CA + Field bean) (285.13 and 289.58 mg kg^{-1}) during 2017 and 2018, respectively. Irrespective of depths, higher soil microbial carbon was maintained under T_6 (CA + Cowpea) during both years. Treatment T_9 (Fodder maize alone) recorded significantly lower soil microbial carbon at all depths of soil.
- ✓ Water soluble carbon was found significantly higher in T_6 (CA + Cowpea) (49.96 and 55.46 mg kg^{-1}) which was followed by T_3 (CA + Field bean) (47.38 and 52.96 mg kg^{-1}) during 2017 and 2018, respectively at 0–15 cm depth of soil. During 2017 and 2018, significantly lower water soluble carbon was recorded in T_9 (Fodder maize alone) (29.61 and 30.79 mg kg^{-1}, respectively) at 0–15 cm depth. Irrespective of depths, T_6 (CA + Cowpea) showed significantly higher buildup of water soluble carbon as compared to rest of the treatments.
- ✓ At 0–15 cm depth of soil, significantly higher active/labile carbon content was maintained under T_6 (CA + Cowpea) (657.12 and 654.98 mg kg^{-1}) which was followed by T_3 (CA + Field bean) (641.53 and 646.29 mg kg^{-1}) during 2017 and 2018, respectively. Significantly lower active/labile carbon content was recorded in T_9 (Fodder maize alone) (468.08 and 474.81 mg kg^{-1}) during 2017 and 2018, respectively. Similar trend was maintained in lower depths of soil.
- ✓ Total carbon in soil at 0–15 cm was significantly higher in CA + Cowpea (7.19 and 7.19 g kg^{-1}) (T_6) followed by CA + Field bean (7.11 and 7.13 g kg^{-1}) (T_3) during 2017 and 2018, respectively. Fodder maize alone (5.77 and 5.80 g kg^{-1}) (T_9) recorded significantly lower total carbon content of soil during 2017 and 2018, respectively. At other depths higher total carbon was maintained under CA + Cowpea (T_6).
- ✓ All the carbon fractions showed decreasing trend with increase in soil depth except soil inorganic carbon which increased with increased soil depth.

- ✓ At 0–15 cm depth, the available N was found significantly higher under CA + Cowpea (T_6) (105.31 and 106.48 mg kg^{-1}) during 2017 and 2018, respectively. This was followed by CA + Field bean (T_3) (104.70 and 106.43 mg kg^{-1}, respectively). Significantly lower available N was recorded under Fodder maize alone (T_9) (54.12 and 58.96 mg kg^{-1}) and CA + Fodder maize (T_2) (62.12 and 63.33 mg kg^{-1}) during 2017 and 2018, respectively.
- ✓ During 2017 and 2018, significantly higher available N at 15–30, 30–60 and 60–90 cm depth was maintained under CA + Cowpea (T_6) (91.33 and 95.90, 70.17 and 73.68, 50.09 and 52.59 mg kg^{-1}, respectively). Significantly lower available N was recorded under Fodder maize alone (T_9) at all depths.
- ✓ Among the different treatments, CA + Cowpea (T_6) recorded significantly higher (39.79 and 43.78 mg kg^{-1}) ammonical nitrogen at 0–15 cm depth followed by T_3 (CA + Field bean) (37.51 and 42.38 mg kg^{-1}) during 2017 and 2018, respectively. Fodder maize alone (T_9) (19.63 and 22.42 mg kg^{-1}) recorded significantly lower ammonical nitrogen content at 0–15 cm depth followed by T_2 (CA + Fodder maize) (21.17 and 22.48 mg kg^{-1}) during 2017 and 2018, respectively.
- ✓ At 15–30, 30–60 and 60–90 cm depth, significantly higher ammonical nitrogen was maintained under CA + Cowpea (T_6) (40.28 and 45.29, 30.59 and 34.77, 24.38 and 25.60 mg kg^{-1}, respectively) during 2017 and 2018, respectively. Fodder maize alone (T_9) maintained significantly lower ammonical nitrogen content at all depths of soil.
- ✓ Nitrate nitrogen content of soil was found higher under CA + Cowpea (T_6) (42.63 and 42.76 mg kg^{-1}) followed by T_3 (CA + Field bean) (39.43 and 38.25 mg kg^{-1}) at 0–15 cm depth during 2017 and 2018, respectively. Fodder maize alone (T_9) (21.17 and 22.02 mg kg^{-1}) recorded significantly lower nitrate nitrogen content at 0–15 cm depth during 2017 and 2018, respectively. At all other depths higher nitrate nitrogen content in soil was maintained under CA + Cowpea (T_6).
- ✓ Higher total nitrogen content at 0–15 cm depth of soil was recorded in CA + Cowpea (T_6) (636.65 and 638.48 mg kg^{-1}) followed by CA + Field bean (T_3) (622.48 and 623.81 mg kg^{-1}) during 2017 and 2018, respectively. Significantly lower total

nitrogen content was recoded under Fodder maize alone (T_9) (457.25 and 465.54 mg kg^{-1}).

- ✓ CA + Cowpea (T_6) maintained a higher total N at 15–30 (581.63 and 580.71 mg kg^{-1}), 30–60 (515.37 and 521.14 mg kg^{-1}) and 60–90 cm (393.65 and 389.33 mg kg^{-1}) depths of soil and is on par with T_2 (CA + Field bean) during 2017 and 2018, respectively. Significantly lower values were recorded under Fodder maize alone (T_9) at all depths.
- ✓ All the nitrogen fractions were found decreased with increase in depth of soil. At all depths higher content of different nitrogen fractions were maintained under CA + Cowpea (T_6).

Soil chemical and biological properties after harvest of crops under custard apple based agri–horticulture system

- ✓ Soil pH and EC was non–significant among the treatments after harvest of the crops during 2017 and 2018. However, in pooled data the soil pH was ranged from 5.27 in CA + Field bean (T_3) to 5.43 in CA + Finger millet (T_1) whereas, EC (dS m^{-1}) was ranged from 0.04 in CA + Finger millet to 0.06 in Custard apple alone treatments.
- ✓ Significantly higher organic carbon content was recorded in CA + Cowpea (T_6) (6.56 and 6.57 g kg^{-1}) which was on par with CA + Field bean (T_3) (6.48 and 6.49 g kg^{-1}) during 2017 and 2018, respectively. Significantly lower organic carbon content was found in Fodder maize alone (4.85 and 4.85 g kg^{-1}) and CA + Fodder maize (5.10 and 5.11 g kg^{-1}) during 2017 and 2018, respectively.
- ✓ After harvest of the crops, CA + Cowpea (T_6) maintained significantly higher (105.31 and 106.48 mg kg^{-1}) available N followed by CA + Field bean (T_3) (104.70 and 106.43 mg kg^{-1}) during 2017 and 2018, respectively. Fodder maize alone (T_9) (54.10 and 58.96 mg kg^{-1}) recorded significantly lower available N in soil during 2017 and 2018, respectively.
- ✓ During 2017 and 2018, significantly higher available P_2O_5 was maintained by CA + Cowpea (T_6) (30.90 and 31.44 mg kg^{-1}, respectively) which was followed by CA + Field bean (T_3) (28.68 and 29.80 mg kg^{-1}, respectively). Significantly lower available

P_2O_5 in soil was recorded in Fodder maize alone (T_9) (13.72 and 12.68 mg kg^{-1}, respectively).

- ✓ CA + Cowpea (T_6) had significantly higher available K_2O (70.28 and 72.64 mg kg^{-1}) followed by T_3 (CA + Field bean) (70.65 and 72.06 mg kg^{-1}) and T_{13} (Cowpea alone) (63.68 and 64.44 mg kg^{-1}) during 2017 and 2018, respectively. Fodder maize alone (T_9) recorded significantly lower available K_2O (43.15 and 41.40 mg kg^{-1}) during 2017 and 2018, respectively.
- ✓ Significantly higher exchangeable Ca (2.53 and 2.59 cmol (p^+) kg^{-1}), Mg (1.25 and 1.31 cmol (p^+) kg^{-1}) and available S (15.41 and 15.88 mg kg^{-1}) was maintained under CA + Cowpea (T_6) during 2017 and 2018, respectively followed by T_3 (CA + Field bean). Significantly lower exchangeable Ca (1.56 and 1.48 cmol (p^+) kg^{-1}), Mg (0.56 and 0.60 cmol (p^+) kg^{-1}) and available S (7.35 and 7.56 mg kg^{-1}) was recorded under Fodder maize alone (T_9) during 2017 and 2018, respectively.
- ✓ CA + Cowpea (T_6) had significantly higher Fe (12.31 and 12.28 mg kg^{-1}), Mn (34.05 and 34.02 mg kg^{-1}), Zn (2.20 and 2.21 mg kg^{-1}) and Cu (1.14 and 1.11 mg kg^{-1}) during 2017 and 2018, respectively. Significantly lower Fe (5.26 and 5.43 mg kg^{-1}), Mn (20.35 and 20.07 mg kg^{-1}), Zn (0.98 and 1.01 mg kg^{-1}) and Cu (0.51 and 0.52 mg kg^{-1}) was recorded in Fodder maize alone (T_9) during 2017 and 2018, respectively.
- ✓ Among the different treatments, significantly higher dehydrogenase activity during 2017 and 2018 was noticed in CA + Cowpea (T_6) (44.63 and 46.86 µg TPF g^{-1} of soil day^{-1}, respectively) followed by T_3 (CA + Field bean) (42.34 and 45.07 µg TPF g^{-1} of soil day^{-1}, respectively). Significantly lower dehydrogenase activity (20.89 and 21.73 µg TPF g^{-1} of soil day^{-1}, respectively) was recorded in Fodder maize alone (T_9).
- ✓ Significantly higher (5.51 and 5.60 µg NH_4–N g^{-1} of soil hr^{-1}) urease activity was found in CA + Cowpea (T_6) during 2017 and 2018, respectively. Fodder maize alone (T_9) maintained significantly lower (3.37 and 3.40 µg NH_4–N g^{-1} of soil hr^{-1}) urease activity during 2017 and 2018, respectively.
- ✓ Significantly higher acid (22.91 and 26.06 µg PNP g^{-1} of soil hr^{-1}) and alkaline (11.21 and 13.77 µg PNP g^{-1} of soil hr^{-1}) phosphatase activity was noticed in CA + Cowpea

(T_6) during 2017 and 2018, respectively. Significantly lower acid (14.28 and 12.15 µg PNP g^{-1} of soil hr^{-1}) and alkaline (5.21 and 4.60 µg PNP g^{-1} of soil hr^{-1}) phosphatase activity was noticed in Fodder maize alone (T_9) during 2017 and 2018, respectively.

- ✓ During 2017 and 2018, significantly higher (293.17 and 295.83 mg kg^{-1}, respectively) microbial biomass C was noticed in CA + Cowpea (T_6) and this was followed by T_3 (CA + Field bean) (285.13 and 289.58 mg kg^{-1}, respectively). Significantly lower (201.49 and 213.55 mg kg^{-1}, respectively) microbial biomass C was recorded under Fodder maize alone (T_9).
- ✓ Microbial biomass N was significantly higher (34.20 and 34.51 mg kg^{-1}) in CA + Cowpea (T_6) which was followed by T_3 (CA + Field bean) (33.27 and 33.78 mg kg^{-1}) during 2017 and 2018, respectively. Significantly lower (23.51 and 24.91 mg kg^{-1}, respectively) microbial biomass N was maintained under Fodder maize alone (T_9).
- ✓ Microbial biomass P was recorded significantly higher (2.98 and 3.13 mg kg^{-1}) in CA + Cowpea (T_6) which was followed by T_3 (CA + Field bean) (2.78 and 2.85 mg kg^{-1}) during 2017 and 2018, respectively. However, Fodder maize alone (T_9) recorded significantly lower (1.26 and 1.31 mg kg^{-1}, respectively) microbial biomass P.

Correlation studies

- ✓ Among the physical properties, aggregate stability ($r=0.944^{**}$), MWD ($r=0.899^{**}$), MWHC ($r=0.897^{**}$) and infiltration rate ($r=0.900^{**}$) had significantly positive correlation with soil organic carbon while the bulk density ($r=-0.832^{**}$) had significantly negative correlation with soil organic carbon.
- ✓ Soil pH had negative correlation with soil organic carbon ($r=-0.588^{**}$), available nitrogen (r=-0.497), phosphorus (r=-0.421) and potassium (r=-0.373).
- ✓ CEC had significantly positive correlation with SOC ($r=0.940^{**}$), TC ($r=0.926^{**}$), MBC ($r=0.876^{**}$), WSC ($r=0.940^{**}$), LC ($r=0.844^{**}$), available N ($r=0.842^{**}$), NH_4–N ($r=0.864^{**}$), NO_3–N ($r=0.989^{**}$) and total nitrogen ($r=0.959^{**}$) but was significantly negatively correlated with SIC ($r=-0.796^{**}$).

- ✓ Available nutrients like nitrogen (r=0.929**), phosphorus (r=0.868) and potassium (r=0.901**) maintained significantly positive correlation with soil organic carbon.
- ✓ Soil organic carbon was maintained significantly positively correlated with soil microbial properties like dehydrogenase activity (r=0.980**), urease activity (r=0.943**), acid phosphatase (r=0.940**), alkaline phosphatase (r=0.967**), MBC (r=0.969**), MBN (r=0.971**) and MBP (r=0.976**). Microbial biomass C was significantly positively correlated with available nutrients as well as other biological properties.
- ✓ Soil organic carbon showed significantly positive correlation with TC (r=0.992**), MBC (r=0.969**), WSC (r=0.984**) and LC (r=0.925**) except SIC (r=-0.809**) which was significantly negatively correlated.
- ✓ The nitrogen fractions like available N (r=0.929**), NH_4–N (r=0.938**), NO_3–N (r=0.962**) and total nitrogen (r=0.943**) shown significantly positive correlation with soil organic carbon.
- ✓ Available nitrogen was significantly and positively correlated with NH_4–N (r=0.883**), NO_3–N (r=0.940**) and total nitrogen (r=0.897**).
- ✓ SIC had significantly negative correlation with other fractions of carbon like SOC (r=-0.809**) TC (r=-0.728**), MBC (r=-0.819**), WSC (r=-0.819**) and LC (r=-0.846**) as well nitrogen fractions.

Yield, nutrient content, total nutrient uptake, SYI, LER, ATER and RWUE under custard apple based agri–horticulture system

- ✓ Yield of custard apple differed significantly due to intercropping. During 2017 and 2018, significantly higher custard apple yield (4374 and 4396 kg ha^{-1}, respectively) was recorded in T_{15} (Custard apple alone) followed by CA + Cowpea (T_6) (4329 and 4375 kg ha^{-1}, respectively) and CA + Field bean (T_3) (4228 and 4345 kg ha^{-1}, respectively). Significantly lower custard apple yield was registered by CA + Fodder maize (T_2) (3800 and 3932 kg ha^{-1}, respectively).

- ✓ During 2017 and 2018, significantly higher CEY (807 and 856 kg ha^{-1}, respectively) was registered under CA + Finger millet (T_1) followed by CA + Chilli (T_5) (715 and 737 kg ha^{-1}, respectively) and CA + Fodder maize (T_2) (490 and 475 kg ha^{-1}, respectively). Significantly lower CEY (185 kg ha^{-1}) was recorded in T_7 (CA + Foxtail millet) during 2017 and in T_4 (CA + Niger) (204 kg ha^{-1}) during 2018.
- ✓ Both grain and straw yield of component crops *viz.,* finger millet, fodder maize, field bean, niger, chilli, cowpea and foxtail millet were higher in their sole crop stands compared to that of intercropping system.
- ✓ Significantly higher nitrogen and phosphorus content of grain was recorded in CA + Field bean (T_3) which was on par T_{10} (Field bean alone) during 2017 and 2018. Significantly lower nitrogen and phosphorus content of grain was registered under CA + Foxtail millet (T_7).
- ✓ Significantly higher potassium content of grain was recorded in Chilli alone (T_{12}) and CA + Chilli (T_5) during 2017 and 2018. Significantly lower potassium content was found under T_8 (Finger millet alone).
- ✓ Among secondary nutrients, field bean (T_3 and T_{10}) registered significantly higher calcium content in grain followed by cowpea (T_6 and T_{13}). Magnesium content of grain during 2017 and 2018 was found to be higher in chilli (T_5 and T_{12}). Whereas, Sulphur content of grain was higher under niger (T_4 and T_{11}) during 2017 and 2018. Significantly lower calcium, magnesium and sulphur content of grain was recorded in foxtail millet (T_7 and T_{14}).
- ✓ Among micronutrient content of grain, significantly higher Fe and Mn content were recorded under finger millet (T_1 and T_8). Foxtail millet (T7 and T14) recorded significantly higher Zn content in grain. However, higher Cu content was noticed chilli (T_5 and T_{12}).
- ✓ Significantly lower Fe and Mn content of grain were recorded under cowpea (T_6 and T_{13}). Whereas, Zn content was found lower under finger millet (T_1 and T_8). However, foxtail millet (T_7 and T_{14}) registered significantly lower Cu content in grain.

- ✓ Significantly higher nitrogen and phosphorus content of haulm was recorded in field bean (T_3 and T_{10}) and Cowpea (T_6 and T_{13}) during 2017 and 2018. Significantly higher potassium content was recorded in stalk of niger (T_{11} and T_4). Significantly lower nitrogen content was registered in stalk of foxtail millet (T_7 and T_{14}) and lower phosphorus was recorded in straw of foxtail millet (T_7 and T_{14}) however, potassium content was found lower under fodder maize (T_2 and T_9).
- ✓ Secondary nutrients content of straw/stalk/haulm varied significantly among the treatments during 2017 and 2018. Among secondary nutrients, significantly higher calcium content was found in haulm of field bean (T_3 and T_{10}) and Cowpea (T_6 and T_{13}) during 2017 and 2018.
- ✓ Magnesium content during 2017 and 2018 was found to be higher in haulm of field bean (T_3 and T_{10}). Whereas, Sulphur content was higher under niger (T_4 and T_{11}) during 2017 and 2018. Significantly lower calcium, magnesium content was recorded in fodder maize (T_9 and T_2) and sulphur content was recorded low in foxtail millet (T_7 and T_{14}).
- ✓ Significantly higher Fe content was found in fodder maize (T_2 and T_9) and higher Mn content was recorded in stalk of chilli (T_5 and T_{12}). Foxtail millet (T_7 and T_{14}) recorded significantly higher Zn content in straw. However, higher Cu content was noticed chilli (T_5 and T_{12}).
- ✓ Pooled data revealed that, significantly higher total uptake of nitrogen, phosphorus and potassium was recorded in Fodder maize alone (T_9) (123.68, 32.49 and 115.49 kg ha^{-1}, respectively) followed by T_{12} (Chilli alone) (85.23, 17.42 and 86.61 kg ha^{-1}, respectively).
- ✓ Significantly lower total nitrogen uptake was recorded in CA + Niger (T_4) (12.29 kg ha^{-1}) followed by T_7 (CA + Foxtail millet) (13.01 kg ha^{-1}). CA + Foxtail millet (T_7) (2.96 kg ha^{-1}) recorded significantly lower uptake of phosphorus. Significantly lower total potassium uptake was recorded under T_7 (CA + Foxtail millet) (16.43 kg ha^{-1}) followed by T_4 (CA + Niger) (21.69 kg ha^{-1}).

- ✓ Significantly higher (45.32 kg ha^{-1}) total calcium uptake was noticed under T_8 (Finger millet alone) and T_{12} (Chilli alone) (42.37 kg ha^{-1}). Significantly lower (6.87 kg ha^{-1}) total calcium uptake was recorded under T_7 (CA + Foxtail millet).
- ✓ Higher (35.89 kg ha^{-1}) total uptake of magnesium was recorded significantly in Chilli alone (T_{12}) followed by T_8 (Finger millet alone) (31.36 kg ha^{-1}). CA + Foxtail millet (T_7) recorded significantly lower total uptake of magnesium (3.85 kg ha^{-1}).
- ✓ Significantly higher (20.18 kg ha^{-1}) total sulphur uptake was recorded in CA + Fodder maize (T_9) followed by T_8 (Finger millet alone) (16.36 kg ha^{-1}). Significantly lower total sulphur uptake was noticed under CA + Foxtail millet (T_7) (2.61 kg ha^{-1}).
- ✓ Significantly higher (1876.63 g ha^{-1}) total Fe uptake was noticed in Fodder maize alone (T_9) which was followed by CA + Fodder maize (T_2) (1280.28 g ha^{-1}). Significantly lower (124.32 g ha^{-1}) total Fe uptake was recorded in CA + Niger (T_4).
- ✓ Chilli alone (T_{12}) recorded significantly higher (588.71 g ha^{-1}) total Mn uptake. Significantly lower (58.34 g ha^{-1}) total Mn uptake was noticed under CA + Cowpea (T_6) treatment.
- ✓ Total Zn uptake was significantly higher (428.21 g ha^{-1}) in Fodder maize alone (T_9). CA + Cowpea (T_6) recorded significantly lower (34.10 g ha^{-1}) total Zn uptake.
- ✓ Total uptake of Cu was found significantly higher (80.37 g ha^{-1}) under Fodder maize alone (T_9). CA + Foxtail millet (T_7) recorded significantly lower (9.58 g ha^{-1}) total Cu uptake.
- ✓ Sustainable yield index varied due to intercropping. CA + Fodder maize (T_2) (1.00) and CA + Chilli (T_5) (1.00) recorded higher SYI as compared to all other treatments. Lower SYI was registered in Foxtail millet alone (T_{14}) (0.73) which was followed by Finger millet alone (T_7) (0.88).
- ✓ Land equivalent ratio (LER) varied significantly due to custard apple based agri–horticulture system. CA + Chilli (T_5) resulted in significantly higher LER (1.60) followed by CA + Niger (T_4) (1.58). Significantly lower LER was recorded in Custard apple alone (T_{15}) (1.0).

- ✓ CA + Chilli (T_5) registered significantly higher ATER (1.32) as compared to all other treatments. Significantly lower ATER was recorded by custard apple alone (T_{15}) (1.00).
- ✓ CA + Finger millet (T_1) recorded highest RWUE (10.08 kg ha–mm^{-1}) followed by CA + Chilli (T_5) (9.87 kg ha–mm^{-1}). Lowest RWUE was registered by Niger alone (T_{11}) (0.61 kg ha–mm^{-1}).

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Research Article

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Influence of Custard Apple (*Annona squamosa* L.) Based Agri-Horticulture System on Intercrop Yield and Soil Properties

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ABSTRACT

An experiment was conducted at All India Co-ordinated Research Project for Dryland Agriculture, Gandhi Krishi Vignana Kendra, Bangalore to assess the effect of custard apple (CA) based Agri-Horticulture system on yield of different crops and soil properties during kharif 2017. The experiment consisted of 15 treatments viz., T_1:CA+finger millet, T_2:CA+fodder maize, T_3:CA+field bean, T_4:CA+niger, T_5:CA+chilli, T_6:CA+cowpea, T_7:CA+foxtail millet, T_8: Finger millet alone, T_9: Fodder maize alone, T_{10}: Field bean alone, T_{11}: Niger alone, T_{12}:Chilli alone, T_{13}: Cowpea alone, T_{14}: Foxtail millet alone and T_{15}: Custard apple alone, replicated thrice using randomised block design.

The results revealed that all crops recorded higher yield in sole treatments compared to their respective intercropping systems. The yield of CA was higher under sole treatment (4374.34 kg ha^{-1}) and lower yields in CA+fodder maize treatment (3800.83 kg ha^{-1}). The custard apple equivalent yield (CEY) was found higher in CA+finger millet treatment (807.14 kg ha^{-1}) followed by CA+chilli treatment (715.01 kg ha^{-1}) and lowest was observed under CA+foxtail millet (132.51 kg ha^{-1}) treatment. Soil available nutrients like nitrogen, phosphorus and potassium were recorder higher under CA+cowpea (262.50, 80.91 and 176.22 kg ha^{-1}, respectively) treatment followed by CA+field bean (258.95, 78.70, 171.39 kg ha^{-1}, respectively). The lowest available nutrients were recorded under fodder maize alone treatment.

Key words: *Custard apple, Intercropping, Equivalent yield, Organic carbon and Available nutrients.*

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INTRODUCTION

Agri-horticulture system is an important approach which not only provides higher yields but also generates additional income as well as improves soil fertility status. Intercropping is an age old practice in India, especially under rainfed conditions, which aims at increasing total productivity per unit area through equitable and judicious use of land resource and farming inputs including labours. The intercropping system besides meeting the various requirements of a farmer, also harnesses the farmer resources efficiently. To get higher yield and returns, to maintain soil health, preserve environment and meet daily food and fodder requirement of human and animal population diversification of cropping system is necessary[8]. In intercropping system due to complimentary effect of crops we can get higher yields and net income. Maintenance of good soil fertility is essential for any crop production system which can be achieved by adopting proper intercropping systems.

Custard apple (*Annona squamosa* L.), a native of Tropical America is widely distributed throughout the tropical and subtropical regions. It has several synonyms such as sithaphal, sharifa, sugar apple, sweet sop etc, and there are more than 70 species which come under the genus *Annona*. India is one of the major producers of custard apple and is not cultivated as extensive plantation in any country. In India, an estimated area and production of custard apple is 19,660 ha and 1,33,050 tonnes, respectively and the productivity is 6.76 tonnes ha^{-1}. The area under custard apple in Karnataka is 1,800 ha with production of 13,400 tonnes and productivity of 7.4 tonnes ha^{-11}. So, the objective of this paper is to see the performance of the different crops under intercropping and sole cropping systems under custard apple based agri-horticulture system and to know the changes in important soil properties under these systems.

MATERIAL AND METHODS

The experiment was conducted at All India Coordinated Research Project for Dryland Agriculture, UAS, GKVK, Bangalore. The centre is situated in the Eastern Dry Zone of Karnataka (Agro-climatic zone V) at 12°58′ North latitude and 77°35′ East longitude with an altitude of 930 m above mean sea level. The experiment was conducted in an eight years old established custard apple orchard with 15 treatments during *kharif* 2017 in randomized complete block design with three replications. The experiment was initiated in *kharif* 2012 and from then onwards the experiment is being continued with fixed treatments. The experiment consisted of 15 treatments *viz.*, T_1:CA+finger millet, T_2:CA+fodder maize, T_3:CA+field bean, T_4:CA+niger, T_5:CA+chilli, T_6:CA+cowpea, T_7:CA+foxtail millet, T_8:Finger millet alone, T_9:Fodder maize alone, T_{10}:Field bean alone, T_{11}:Niger alone, T_{12}:Chilli alone, T_{13}: Cowpea alone, T_{14}: Foxtail millet alone and T_{15}: Custard apple alone. All the package of practices including fertilizer application was followed as per the university recommendation. The variety, spacing and recommended dose of fertilizer applied are presented in **Table 1**.

The experiment was devised as per the treatments and planting was taken up during *kharif* 2017, sole as well as intercropping. The recommended dose of nitrogen was applied as two equal splits, one as basal dose and another at 45 days after sowing/transplanting in case of finger millet, fodder maize and chilli. Well decomposed farmyard manure @ 7.5 t/ha was applied as per the treatment specifications two weeks before transplanting/sowing of the crops and was mixed thoroughly with soil. The nutrients were applied in the form of urea, diammonium phosphate and muriate of potash. The initial soil properties (as recorded in 2012) of the experimental site[10] indicated that the soil was slightly acidic (pH-5.6) in reaction with low organic matter (0.40%) content with normal electrical conductivity (0.07 dS m^{-1}). Available nitrogen (224.0 kg ha^{-1}) was low with high phosphorus (72.0 kg ha^{-1}) and medium potassium (163.0 kg ha^{-1}). The soil sampling was done before sowing at 0-15 cm depth and was analysed for its pH, electrical conductivity, organic carbon, available

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nitrogen, phosphorus and potassium following standard protocols.

Statistical analysis: The data collected were analysed statistically following the procedure as described by Panse and Sukhatme[9]. The level of significance used in 'F' and 't' test was *P=0.05*. Critical differences were calculated using the 't' test wherever 'F' test was significant.

RESULTS AND DISCUSSION

Effect of agri-horticulture system on yield of custard apple, intercrop and sole crop yield and Custard apple equivalent yield (CEY)

The results regarding yield of custard apple, intercrop and sole crop yield of different crops and CEY are presented in **Table 2**.

Custard apple yield under agri-horticulture system

The custard apple yield was varied significantly among different treatments **(Table 2)**. Higher yield of custard apple was recorded in custard apple alone treatment (4374.34 kg ha^{-1}) compared to custard apple under intercropping systems. Under different intercropping systems, the yield of custard apple was higher in CA+cowpea (4329.70 kg ha^{-1}) treatment followed by CA+field bean (4228.28 kg ha^{-1}). Custard apple yield was found on par under CA+chilli, CA+niger, CA+finger millet and CA+foxtail millet. Significantly lower yield was recorder in CA+fodder maize (3800.83 kg ha^{-1}) treatment. The decreased custard apple yield under intercropping system compared to sole crop might be due to competition among main and component crop for different sources. Lal *et al.*[5], Munde *et al.*[7] and Swain *et al.*[13] also observed reduction in yield due to intercropping systems.

Intercrop and sole crop yield under agri-horticulture system

The yields of different crops were varied due to intercropping and sole cropping system **(Table 2)**. Generally, the yield different crops were higher under sole cropping system compared to the intercropping. The differences in the yield between sole cropping and intercropping were mainly as a consequence of differences in the plant population. Decreased yield of different crops under intercropping system compared to sole cropping might be attributed to fact that the crops under intercropping might face competition from main crop (Custard apple) for different sources like light, moisture, nutrients and spacing as well as shade effect of the custard apple. Das *et al.*[4] and Chauhan *et al.*[3] also reported the reduced yield of agronomic crops under intercropping systems compared to their sole crops.

Custard apple equivalent yield (CEY) under agri-horticulture system

CEY was used to convert the yield of component/intercrop into main crop yield (Custard apple). The data pertaining to the CEY is presented in **Table 2**. CEY varied significantly among different intercropping systems. The treatment CA+finger millet (807.14 kg ha^{-1}) recorded significantly higher CEY followed by CA+chilli (715.01 kg ha^{-1}) and CA+fodder maize (490.91 kg ha^{-1}). Lower CEY was recorded in CA+foxtail millet, CA+field bean, CA+niger and CA+cowpea. The higher CEY in CA+finger millet (807.14 kg ha^{-1}) was attributed to the higher yield of finger millet since CEY is directly related to the yield and price of the produce. The higher CEY indicates the additional higher yield of the main crop (Custard apple) compared to the actual yield. Higher custard apple equivalent yield under intercropping systems was attributed to yield advantages achieved in intercropping system. This is in accordance with the findings of Sujatha *et al.*[12], Avinash *et al.*[2] and Ramulu[10].

Soil properties under agri-horticulture system

Soil properties especially organic carbon, available nitrogen, phosphorus and potassium varied significantly among different treatments. The data pertaining to the soil properties is presented in the **Table 3 and 4**.

Soil pH, electrical conductivity and organic carbon content of soil

The soil pH and electrical conductivity was found to be non-significant among different

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treatments (**Table 3**). The organic carbon content of soil varied significantly among different treatments. Generally higher organic carbon was found in intercropping systems compared to sole crops. Significantly higher organic carbon content was recorded in CA+cowpea (0.65%) treatment which was on par with CA+field bean (0.64%), cowpea alone (0.62%) and field bean alone (0.61%). Significantly lower organic carbon content was found in treatments fodder maize alone (0.48 %) and CA+fodder maize (0.50 %). The higher organic carbon under intercropping systems was due to the higher addition of crop residues both from main crop and intercrop, better soil and moisture conservation and less oxidation due to high intensity sunlight which is higher under sole cropping system. Similar results were reported by Das *et al.*[4] and Ramulu[10].

Available nitrogen, phosphorus and potassium in soil

Available nitrogen, phosphorus and potassium in soil among different treatments under custard apple based agri-horticulture system varied significantly and the values are presented in **Table 4**. Among the different treatments, significantly higher available nitrogen, phosphorus and potassium was recorder in treatment CA+cowpea (262.50, 80.91, 176.22 kg ha^{-1}, respectively) followed by CA+field bean (258.95, 78.70, 171.39 kg ha^{-1}, respectively), cowpea alone (244.05, 74.24, 168.22 kg ha^{-1}, respectively) and field bean alone (246.34, 73.41, 165.23 kg ha^{-1}, respectively). Generally higher available nitrogen, phosphorus and potassium were observed under intercropping systems compared to the sole cropping. Significantly lower available nitrogen, phosphorus and potassium in soil was found in treatment fodder maize alone (167.31, 50.83, 116.60 kg ha^{-1}, respectively) and CA+fodder maize (172.16, 48.64, 120.69 kg ha^{-1}, respectively).

This could be attributed to addition of nitrogen to soil through symbiotic nitrogen fixation and addition of organic matter in the form of leaf litter by the legume components. Due to higher biomass production, higher nutrient uptake and as an exhaustive crop fodder maize both under sole and intercropping recorded lower available nutrients. Similar results were obtained by Lal *et al.*[5], Avinash *et al.*[2] and Lehmann *et al.*[6]. Srinivasan *et al.*[11] reported that presence of legumes in the mixture benefits the associated non-legumes as the legumes provide a portion of biologically fixed nitrogen to non-legume components. Further, legumes increase the soil nitrogen content and help to maintain soil fertility. Tree based land use system has the potential to improve soil fertility.

Table 1: Varieties, spacing and fertilizer dosage used for different crops

Crops	Variety	Spacing	RDF (NPK kg ha^{-1})
Custard apple	Arka Sahana	5.0 m x 5.0 m	250:125:125 (g $plant^{-1}$)
Finger millet	GPU-28	30 cm x 10 cm	50:40:25
Fodder maize	S. A.Tall	30 cm x 15 cm	100:50:50
Field bean	Hebbal avare-4	45 cm x 30 cm	25:50:25
Niger	No. 71	30 cm x 10 cm	20:40:20
Chilli	Samruddhi	45 cm x 45 cm	100:50:50
Cowpea	IT 38956-1	45 cm x 15 cm	25:50:25
Foxtail millet	R. S-118	30 cm x 10 cm	40:40:00

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Table 2: Custard apple yield, Intercrop and sole crop yield and Custard apple equivalent yield as influenced by different intercrops in agri-horticulture system (2017)

Treatments	Custard apple yield (kg ha^{-1})	Intercrop and sole crop yield (kg ha^{-1})	Custard apple equivalent yield (kg ha^{-1})
T_1: CA + finger millet	4024.37	1614.28	807.14
T_2: CA + fodder maize	3800.83	29454.73	490.91
T_3: CA + field bean	4228.28	348.03	139.21
T_4: CA + niger	4144.73	186.1967	186.20
T_5: CA + chilli	4113.40	2860.02	715.01
T_6: CA + cowpea	4329.70	375.75	187.88
T_7: CA + foxtail millet	4069.02	397.52	132.51
T_8: Finger millet alone	----	2931.16	----
T_9: Fodder maize alone	----	47744.55	----
T_{10}: Field bean alone	----	726.97	----
T_{11}: Niger alone	----	289.39	----
T_{12}: Chilli alone	----	4157.97	----
T_{13}: Cowpea alone	----	837.54	----
T_{14}: Foxtail millet alone	----	813.13	----
T_{15}: Custard apple alone	4374.34	4374.34	----
S.Em±	**96.88**	----	**25.59**
CD at 5 % (*p=0.05*)	**293.86**	----	**79.74**

Table 3: Soil pH, electrical conductivity and organic carbon as influenced by different intercrops in agri-horticulture system (2017)

Treatments	Soil pH	EC (dS/m)	Organic carbon (%)
T_1: CA + finger millet	5.51	0.05	0.57
T_2: CA + fodder maize	5.48	0.04	0.50
T_3: CA + field bean	5.45	0.06	0.64
T_4: CA + niger	5.49	0.05	0.54
T_5: CA + chilli	5.50	0.06	0.55
T_6: CA + cowpea	5.43	0.05	0.65
T_7: CA + foxtail millet	5.53	0.06	0.53
T_8: Finger millet alone	5.49	0.06	0.55
T_9: Fodder maize alone	5.47	0.05	0.48
T_{10}: Field bean alone	5.45	0.05	0.61
T_{11}: Niger alone	5.48	0.06	0.51
T_{12}: Chilli alone	5.49	0.07	0.53
T_{13}: Cowpea alone	5.46	0.06	0.62
T_{14}: Foxtail millet alone	5.49	0.05	0.51
T_{15}: Custard apple alone	5.53	0.07	0.51
S.Em±	**0.05**	**0.01**	**0.03**
CD at 5 % (*p=0.05*)	**NS***	**NS**	**0.08**

***NS**: Non-significant

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Table 4: Available nutrients (N, P_2O_5 and K_2O) in soil as affected by different intercrops in agri-horticulture system (2017)

Treatments	Available nitrogen (kg ha^{-1})	Available phosphorus (kg ha^{-1})	Available potassium (kg ha^{-1})
T_1: CA + finger millet	214.69	71.31	159.78
T_2: CA + fodder maize	172.16	48.64	120.69
T_3: CA + field bean	258.95	78.70	171.39
T_4: CA + niger	213.96	66.24	142.11
T_5: CA + chilli	223.01	72.05	136.59
T_6: CA + cowpea	262.50	80.91	176.22
T_7: CA + foxtail millet	209.79	69.67	146.23
T_8: Finger millet alone	205.50	65.01	147.09
T_9: Fodder maize alone	167.31	50.83	116.60
T_{10}: Field bean alone	246.34	73.41	165.23
T_{11}: Niger alone	205.77	60.34	135.74
T_{12}: Chilli alone	215.11	70.76	136.78
T_{13}: Cowpea alone	244.05	74.24	168.22
T_{14}: Foxtail millet alone	199.53	65.02	140.19
T_{15}: Custard apple alone	201.66	54.25	135.72
S.Em±	**10.47**	**4.97**	**8.30**
CD at 5 % (*p=0.05*)	**30.32**	**14.39**	**24.05**

CONCLUSION

Agri-horticulture system is an essential approach to have higher farm income and for maintaining better soil fertility. Even though the yield of individual crops including custard apple was higher under sole crops but the additional yield from component crops is an added advantage under intercropping system. The better soil and water conservation and reduced oxidation loss of native organic matter in soil and legume components under agri-horticulture system results in better soil properties like available nutrients, organic carbon and other soil physical and biological properties. So it is concluded that the custard apple based agri-horticulture system is very important especially under dryland situations to get the higher farm returns as well as improving the soil fertility.

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Depth-wise distribution of soil carbon and nitrogen under custard apple (*Annona squamosa* L.) based Agri-horticulture system

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Abstract
An experiment was conducted at All India Co-ordinated Research Project for Dryland Agriculture, Gandhi Krishi Vignana Kendra, Bangalore during *kharif* 2017 to assess the effect of custard apple (CA) based agri-horticulture system on distribution of carbon and nitrogen in soil at different depths. The experiment consisted of 15 treatments *viz.*, T_1:CA+Finger millet, T_2:CA+Fodder maize, T_3:CA+Field bean, T_4:CA+Niger, T_5:CA+Chilli, T_6:CA+Cowpea, T_7:CA+Foxtail millet, T_8: Finger millet alone, T_9: Fodder maize alone, T_{10}: Field bean alone, T_{11}: Niger alone, T_{12}:Chilli alone, T_{13}: Cowpea alone, T_{14}: Foxtail millet alone and T_{15}: Custard apple alone, replicated thrice using randomised block design.
The results of the investigation revealed that carbon and nitrogen at different depths varied significantly among different treatments under custard apple based agri-horticulture system. At 0-15, 15-30, 30-60 and 60-90 cm depth of soil, the organic carbon (6.11, 5.77, 4.15 and 3.12 g kg^{-1}, respectively) and total carbon (6.74, 6.72, 5.40 and 4.49 g kg^{-1}, respectively) were found higher under CA+Cowpea intercropping system. Lower values of organic carbon (4.42, 4.01, 2.73 and 1.94 g kg^{-1}, respectively) and total carbon (5.34, 5.36, 4.14 and 3.50 g kg^{-1}, respectively) were recorded in Fodder maize alone system. Higher inorganic carbon content at 0-15, 15-30, 30-60 and 60-90 cm depth of soil was recorded under Fodder maize alone (0.92, 1.35, 1.41 and 1.56 g kg^{-1}, respectively) treatment and lower values were recorded in CA+Cowpea (0.63, 0.95, 1.25 and 1.37 g kg^{-1}, respectively) intercropping system. At 0-15, 15-30, 30-60 and 60-90 cm depth of soil, higher available nitrogen (105.31, 91.33, 70.13 and 50.09 mg kg^{-1}, respectively) and total nitrogen (636.65, 581.63, 515.37 and 393.65 mg kg^{-1}, respectively) were recorded under CA+Cowpea intercropping system and lower values were under Fodder maize alone treatment.

Keywords: Custard apple, intercropping, carbon, nitrogen and soil depth

Introduction
Intensive cropping over the years encourages oxidative losses of carbon due to continuous soil disturbance, while cropping results in large scale addition of carbon to the soil through addition of crop residues which either results in net addition or depletion of soil carbon stocks (Majumder *et al.*, 2008) [13]. Maintenance of good soil fertility is essential for any crop production system which can be achieved by adopting proper intercropping systems (Lal, 2002) [9]. Agri-horticulture system is an important approach which not only provides higher yields but also generates additional income as well as improves soil fertility status. Under dryland situations it is very difficult to maintain adequate levels of organic matter in soil. Agricultural practices for enhancing SOC must either increase organic matter inputs to the soil, decrease decomposition of soil organic matter (SOM) and oxidation of SOC or a combination of both (Paustian *et al.*, 2000) [15]. Hence, adoption of proper cropping systems which enhance carbon sequestration become essential.
The soil organic carbon is the principal component which determines the soil fertility and productivity status of soil and it varies from soil to soil due to variation in climate, vegetation and management practices. On the other hand nitrogen is a major constituent of several of the most important substances which occur in plants. Present study was conducted in red soils of order Alfisols in Karnataka which comes under tropical situation. In India, Alfisols cover an area of 42 m ha, and are predominant in the states of Andhra Pradesh, Karnataka, Madhya Pradesh, Tamil Nadu and Uttar Pradesh (Bhattacharyya *et al.*, 2013)[3]. So, the present study

was conducted with to check the influence of custard apple based agri-horticulture system on distribution of carbon and nitrogen in soil at different depths.

Material and Methods

The experiment was conducted at All India Coordinated Research Project for Dryland Agriculture (AICRPDA), UAS, GKVK, Bangalore. The centre is situated in the Eastern Dry Zone of Karnataka (Agro-climatic zone V) at 12°58′ North latitude and 77°35′ East longitude with an altitude of 930 m above mean sea level. The experiment was initiated in *kharif* 2012 in a custard apple orchard which was planted in 2009 with 15 treatments *viz.,* T_1: CA+Finger millet, T_2: CA+Fodder maize, T_3: CA+Field bean, T_4: CA+Niger, T_5: CA+Chilli, T_6: CA+Cowpea, T_7: CA+Foxtail millet, T_8: Finger millet alone, T_9: Fodder maize alone, T_{10}: Field bean alone, T_{11}: Niger alone, T_{12}: Chilli alone, T_{13}: Cowpea alone, T_{14}: Foxtail millet alone and T_{15}: Custard apple alone, in randomized complete block design with three replications and from then onwards the experiment is being continued with the same treatments. All the package of practices including fertilizer application was followed as per the university recommendation. The variety, spacing and recommended dose of fertilizer applied are presented in table 1.

The initial soil properties (as recorded in 2012) of the experimental site (Ramulu, 2014) [19] indicated that the soil was slightly acidic (pH-5.6) in reaction with low organic carbon (4.0 g kg^{-1}) content with normal electrical conductivity (0.07 dS m^{-1}). Available nitrogen (100 mg kg^{-1}) was low with high phosphorus (32.14 mg kg^{-1}) and medium potassium (72.76 g kg^{-1}). The soil sampling was done before sowing during *kharif* 2017 at 0-15 cm depth and was analysed for its pH, electrical conductivity, organic carbon, available nutrients by adopting standard protocols.

Table 1: Varieties, spacing and fertilizer dosage used for different crops

Crops	Variety	Spacing	RDF (NPK kg ha^{-1})
Custard apple (CA)	Arka Sahan	5.0 m x 5.0 m	125:62.50:62.50
Finger millet	GPU-28	30 cm x 10 cm	50:40:25
Fodder maize	S. A.Tall	30 cm x 15 cm	100:50:50
Field bean	Hebbal avare-4	45 cm x 30 cm	25:50:25
Niger	No. 71	30 cm x 10 cm	20:40:20
Chilli	Samruddhi	45 cm x 45 cm	100:50:50
Cowpea	IT 38956-1	45 cm x 15 cm	25:50:25
Foxtail millet	R. S-118	30 cm x 10 cm	40:40:00

To study the carbon and nitrogen distribution in soil, soil sampling was done after harvest of crops during *kharif* 2017 at four depths *viz.,* 0-15, 15-30, 30-60 and 60-90 cm. The soil samples collected were analysed for organic carbon, inorganic carbon, total carbon, available nitrogen and total nitrogen content. Organic carbon was estimated by Walkley and Black's wet oxidation method (Jackson, 1973) [7] and expressed in gram per kg of soil. Acid neutralization method or rapid titration method of Piper (1944) [16] was used for estimation of soil inorganic carbon content. Total carbon was calculated by adding both organic and inorganic carbon.

Statistical analysis: The data collected were analysed statistically following the procedure as described by Panse and Sukhatme (1967) [14]. The level of significance used in 'F' and 't' test was *P=0.05*. Critical differences were calculated using the 't' test wherever 'F' test was significant.

Result and Discussion

Soil pH, electrical conductivity and organic carbon content of soil under custard apple based agri-horticulture system

It was found that the soil pH and electrical conductivity was non-significant among different treatments (Table 2). The organic carbon content of soil varied significantly among different treatments. In general intercropping systems recorded higher organic carbon content compared to sole crops. Significantly higher organic carbon content was recorded in CA+Cowpea (6.54 g kg^{-1}) treatment which was on par with CA+Field bean (6.44 g kg^{-1}), cowpea alone (6.28 g kg^{-1}) and field bean alone (6.16 g kg^{-1}). Significantly lower organic carbon content was found in treatments Fodder maize alone (4.83 g kg^{-1}) and CA+Fodder maize (5.05 g kg^{-1}). Due to higher addition of crop residues both from main crop and intercrop, better soil and moisture conservation and less oxidation of organic matter due to high vegetative cover, the intercropping systems recorded higher organic carbon content than sole cropping systems. Similar results were also reported by Das *et al.* (2011) [6] and Ramulu (2014) [19].

Table 2: Influence of custard apple based agri-horticulture system on soil pH, electrical conductivity (EC) and organic carbon content of soil.

Treatments	Soil pH	EC (dS m^{-1})	OC (g kg^{-1})
T_1: CA + Finger millet	5.51	0.05	5.72
T_2: CA + Fodder maize	5.48	0.04	5.05
T_3: CA + Field bean	5.45	0.06	6.44
T_4: CA + Niger	5.49	0.05	5.47
T_5: CA + Chilli	5.50	0.06	5.53
T_6: CA + Cowpea	5.43	0.05	6.54
T_7: CA + Foxtail millet	5.53	0.06	5.31
T_8: Finger millet alone	5.49	0.06	5.55
T_9: Fodder maize alone	5.47	0.05	4.83
T_{10}: Field bean alone	5.45	0.05	6.16
T_{11}: Niger alone	5.48	0.06	5.13
T_{12}: Chilli alone	5.49	0.07	5.37
T_{13}: Cowpea alone	5.46	0.06	6.28
T_{14}: Foxtail millet alone	5.49	0.05	5.16

T_{15}: Custard apple alone	5.53	0.07	5.14
S.Em±	0.05	0.01	0.27
CD at 5 % (*p=0.05*)	NS	NS	0.78

Table 3: Influence of custard apple based agri-horticulture system on available nutrients of soil

Treatments	Available N	Available P_2O_5	Available K_2O	Exch. Ca	Exch. Mg	Available Sulphur
	(mg kg^{-1})			[cmol (p^+) kg^{-1}]		(ppm)
T_1: CA + Finger millet	95.84	31.84	71.33	3.11	2.08	16.10
T_2: CA + Fodder maize	76.86	21.72	53.88	2.86	1.54	13.13
T_3: CA + Field bean	115.60	35.13	76.51	3.38	2.13	19.13
T_4: CA + Niger	95.52	29.57	63.44	2.94	1.91	16.57
T_5: CA + Chilli	99.56	32.17	60.98	2.89	1.82	17.40
T_6: CA + Cowpea	117.19	36.12	78.67	3.36	2.14	19.77
T_7: CA + Foxtail millet	93.65	31.10	65.28	3.12	1.92	16.80
T_8: Finger millet alone	91.74	29.02	65.67	2.95	1.98	16.53
T_9: Fodder maize alone	74.69	22.69	52.06	2.71	1.43	12.30
T_{10}: Field bean alone	109.97	32.77	73.76	3.34	2.08	19.00
T_{11}: Niger alone	91.86	26.94	60.60	2.87	1.93	16.17
T_{12}: Chilli alone	96.03	31.59	61.06	2.80	1.77	16.77
T_{13}: Cowpea alone	108.95	33.14	75.10	3.35	2.04	19.10
T_{14}: Foxtail millet alone	89.08	29.03	62.59	2.99	1.94	16.67
T_{15}: Custard apple alone	90.03	24.22	60.59	2.84	1.64	17.17
S.Em±	4.67	2.22	3.71	0.15	0.09	0.85
CD at 5 % (*p=0.05*)	13.54	6.43	10.74	0.42	0.26	2.48

Available nutrients in soil under custard apple based agri-horticulture system

Available nitrogen, phosphorus and potassium in soil among different treatments under custard apple based agri-horticulture system varied significantly and the values are presented in Table 3. Among the different treatments, significantly higher available nitrogen, phosphorus and potassium was recorder in treatment CA+Cowpea (117.19, 36.12 and 78.67 mg kg^{-1}, respectively) followed by CA+Field bean (115.60, 35.13 and 76.51 mg kg^{-1}, respectively), Cowpea alone (108.95, 33.14 and 75.10 mg kg^{-1}, respectively) and field bean alone (109.97, 32.77 and 73.76 mg kg^{-1}, respectively). Generally higher available nitrogen, phosphorus and potassium were observed under intercropping systems compared to the sole cropping. Significantly lower available nitrogen, phosphorus and potassium in soil was found in treatment fodder maize alone (74.69, 22.69 and 52.06 mg kg^{-1}, respectively) and CA+Fodder maize (76.86, 21.72 and 53.88 mg kg^{-1}, respectively).

There was a significant difference among the treatments with respect to exchangeable calcium, magnesium and available sulphur (Table 3). Significantly higher exchangeable (cmol (p^+) kg^{-1}) calcium, magnesium and available sulphur (ppm) was recorded under CA+Cowpea (3.36, 2.14 and 19.77, respectively) and CA+Field bean (3.38, 2.13 and 19.13, respectively) followed by cowpea alone and field bean alone. A significantly lower exchangeable (cmol (p^+) kg^{-1}) calcium, magnesium and available sulphur (ppm) was recorded under fodder maize alone (2.71, 1.43 and 12.30, respectively) and CA+Fodder maize (2.86, 1.54 and 13.13, respectively).

Higher available nutrients under CA+Cowpea and CA+Field bean systems might be attributed to addition of nitrogen to soil through symbiotic nitrogen fixation and addition of organic matter in the form of leaf litter by the legume components. Due to higher biomass production, higher nutrient uptake and as an exhaustive crop, fodder maize both under sole and intercropping recorded lower available nutrients. The organic acids released through decomposition of leaf litter reduce the metal ions through chelation in soil and they compete for exchange sites, thus, releasing P from exchangeable sites in soil resulted in improved P availability. Higher availability of K, exchangeable Ca, Mg and available S under intercropping systems is attributed to liberation of these nutrients from decomposition of leaf litter as well as solubilization of insoluble forms of K present in soil due to organic decomposition products. Similar results were obtained by Lal *et al.* (2011) [10], Avinash *et al.* (2013) [1] and Lehmann *et al.* (2014) [11]. Srinivasan *et al.* (2010) [23] reported that presence of legumes in the mixture benefits the associated non-legumes as the legumes provide a portion of biologically fixed nitrogen to non-legume components. Further, legumes increase the soil nitrogen content and help to maintain soil fertility. Tree based land use system has the potential to improve soil fertility.

Depth-wise distribution of carbon in soil under custard apple based agri-horticulture system

Organic carbon content of soil

The custard apple based agri-horticulture system significantly influenced the organic carbon content of the soil at different depths (Table 4). At 0-15 cm soil depth, CA+Cowpea (6.56 g kg^{-1}) recorded significantly higher organic carbon in soil followed by CA+Field bean (6.48 g kg^{-1}), cowpea alone (6.32 g kg^{-1}) and field bean alone (6.20 g kg^{-1}). Compared to legume crop treatments the fodder maize alone (4.42 g kg^{-1}) recorded significantly lower organic carbon content followed by CA+Fodder maize (4.85 g kg^{-1}) but it was on par with other treatments which have higher values than fodder maize alone. Cowpea and field bean being leguminous deep–rooted crops has higher root C–input and higher addition of crop residue. Besides this, a part of legume root is usually un–decomposable and thereby enrich soil organic carbon. These findings are in accordance with Ramesh and Chandrasekaran (2004) [18] who reported that mungbean crops enriched soil carbon pools.

Table 4: Organic Carbon (g kg^{-1}) distribution in soil at different depths under custard apple based agri-horticulture system

Treatments	Soil depth (cm)			
	0-15	15-30	30-60	60-90
T_1: CA + Finger millet	5.77	5.35	3.42	2.35
T_2: CA + Fodder maize	5.10	4.65	2.90	2.19
T_3: CA + Field bean	6.48	6.09	4.13	2.84
T_4: CA + Niger	5.49	5.16	3.07	2.31
T_5: CA + Chilli	5.58	5.02	3.12	2.32
T_6: CA + Cowpea	6.56	6.11	4.15	3.12
T_7: CA + Foxtail millet	5.36	4.83	3.21	2.33
T_8: Finger millet alone	5.57	4.92	3.10	2.29
T_9: Fodder maize alone	4.85	4.41	2.73	1.94
T_{10}: Field bean alone	6.20	5.84	3.89	2.68
T_{11}: Niger alone	5.16	4.76	3.16	2.21
T_{12}: Chilli alone	5.42	4.91	3.07	2.19
T_{13}: Cowpea alone	6.32	5.95	3.94	2.70
T_{14}: Foxtail millet alone	5.19	4.66	3.02	2.18
T_{15}: Custard apple alone	5.16	4.59	2.82	2.06
S.Em±	0.27	0.26	0.24	0.12
CD at 5 % (*p=0.05*)	0.78	0.76	0.69	0.35

Generally, it was observed that the intercropping systems maintained a higher organic carbon content in soil than the sole cropping systems. The increase in organic carbon under custard apple based intercropping systems might be due to the increased quantity of plant residues addition through litterfall and higher root biomass from both trees and agriculture crops and reduced soil disturbances. The leaf litter added under custard apple based intercropping systems also acts as mulch, cooling soil surface and reducing soil C oxidation. But under sole cropping system due to direct exposer of soil to sunlight increases the oxidation loss of organic carbon. Hence, these maintained lower organic carbon level in soil. Similar results also reported by Liao and Boutton (2008) [12].

At lower depths (15-30, 30-60 and 60-90 cm) of soil, significantly higher organic carbon was maintained under CA+Cowpea (6.11, 4.15 and 3.12 g kg^{-1}, respectively) treatments compared to other treatments. Lower organic carbon content was recorder at all depths under fodder maize alone (4.41, 2.73 and 1.94 g kg^{-1}, respectively). Irrespective of treatments, organic carbon content was decreased with increase in soil depth. The decrease in organic carbon status with depth might be due to the fact that most of the litterfall and organic matter addition occurs on the surface and very little is incorporated in deeper layers except for addition of C through the decomposing plant roots. Therefore, the build-up of soil organic carbon content was more in the surface layer due to more addition of organic matter, root biomass, root exudates and it decreased with depth (Kaur *et al.,* 2008 [8], Brar *et al.,* 2013) [4]. The presence of organic carbon content even at lower depths of soil might be due to the downward movement of soluble OM originating from top soil (Chantigny, 2003) [5].

Inorganic carbon content of soil

Inorganic forms of carbon are generally derived from soil parent material. Inorganic carbon forms are present in soils and sediments typically as carbonates especially, as calcium carbonate. Under custard apple based agri-horticulture system, there was a significant difference among the treatments with respect to the inorganic carbon content of soil (Table 5).

Table 5: Inorganic Carbon (g kg^{-1}) distribution in soil at different depths under custard apple based agri-horticulture system

Treatments	Soil depth (cm)			
	0-15	**15-30**	**30-60**	**60-90**
T_1: CA + Finger millet	0.73	1.14	1.33	1.48
T_2: CA + Fodder maize	0.89	1.36	1.39	1.55
T_3: CA + Field bean	0.63	0.90	1.26	1.39
T_4: CA + Niger	0.74	1.11	1.35	1.46
T_5: CA + Chilli	0.70	1.15	1.31	1.44
T_6: CA + Cowpea	0.63	0.95	1.25	1.37
T_7: CA + Foxtail millet	0.71	1.13	1.35	1.46
T_8: Finger millet alone	0.76	1.15	1.32	1.50
T_9: Fodder maize alone	0.92	1.35	1.41	1.56
T_{10}: Field bean alone	0.65	1.03	1.26	1.39
T_{11}: Niger alone	0.70	1.16	1.37	1.45
T_{12}: Chilli alone	0.71	1.18	1.35	1.47
T_{13}: Cowpea alone	0.62	1.03	1.28	1.40
T_{14}: Foxtail millet alone	0.75	1.17	1.36	1.46
T_{15}: Custard apple alone	0.90	1.24	1.43	1.54
S.Em±	0.04	0.06	0.07	0.07
CD at 5 % (*p=0.05*)	0.11	0.18	NS	NS

At 0-15 cm soil depth, significantly higher inorganic carbon was recorded under fodder maize alone (0.92 g kg^{-1}) followed by CA alone (0.90 g kg^{-1}) and CA+Fodder maize (0.89 g kg^{-1}) compared to all other treatments. The treatments finger millet alone (0.76 g kg^{-1}), foxtail millet alone (0.75 g kg^{-1}), chilli alone (0.71 g kg^{-1}) and Ca+Niger (0.74 g kg^{-1}) were found to be on par with each other. Lower inorganic carbon content was recorded in CA+Cowpea (0.63 g kg^{-1}) and other legume crop treatments. Soil inorganic carbon content was increased with increase in soil depth. At 15-30 cm depth CA+Fodder maize (1.36 g kg^{-1}) and fodder maize alone (1.35 g kg^{-1}) maintained a higher inorganic carbon content compared to all other treatments. At 30-60 and 60-90 cm soil depth the inorganic carbon content of the soil was non-significant among the treatments but higher values were recorded under fodder maize alone and CA+Fodder maize.

Generally, it was observed that the inorganic carbon content was lower wherever there was a higher organic carbon content. This might be due to the production of organic acids during organic matter decomposition which lead to dissolution as well as due to decalcification process, the inorganic carbon leached to lower layers of soil. Hence, the inorganic carbon content was found higher at lower layers of soil (Sartori *et al.,* 2007) [21].

Total carbon content of soil

Total carbon in soil represents the organic carbon plus inorganic carbon in soil. There was a significant difference among the treatments for total carbon under custard apple based agri-horticulture system (Table 6).

Significantly higher total carbon content in soil at 0-15 cm depth was observed under CA+Cowpea (7.19 g kg^{-1}) followed by CA+Field bean (7.11 g kg^{-1}), cowpea alone (6.94 g kg^{-1}) and field bean alone (6.85 g kg^{-1}). Significantly lower values of total carbon were observed in fodder maize alone (5.77 g kg^{-1}) at 0-15 cm soil depth. All remaining treatments were found on par with each other.

At 15-30 and 30-60 cm depths of soil, CA+Cowpea (7.06 and 5.40 g kg^{-1}, respectively) and CA+Field bean (6.99 and 5.39 g kg^{-1}, respectively) recorded higher total carbon than other treatments. Significantly lower total carbon was recorded in fodder maize alone (5.76 and 4.14 g kg^{-1}) at 15-30 and 30-60 cm depths of soil, respectively. At 60-90 cm depth the total

carbon was found non-significant among the different treatments.

The total carbon content of the soil was higher at surface soil might be due to higher addition of organic matter and leaf litter from custard apple as well as from intercrops. The total carbon content of the soil was decreased with increase in soil depth (from 0 to 90 cm). The decrease in total carbon content in soil with depth might be due to lower incorporation of organic matter at lower depths of soil (Kaur *et al.,* 2008)[8].

Table 6: Total carbon (g kg^{-1}) distribution in soil at different depths under custard apple based agri-horticulture system

Treatments	Soil depth (cm)			
	0-15	15-30	30-60	60-90
T_1: CA + Finger millet	6.50	6.49	4.75	3.83
T_2: CA + Fodder maize	5.99	6.01	4.29	3.74
T_3: CA + Field bean	7.11	6.99	5.39	4.23
T_4: CA + Niger	6.23	6.27	4.42	3.77
T_5: CA + Chilli	6.28	6.17	4.43	3.76
T_6: CA + Cowpea	7.19	7.06	5.40	4.49
T_7: CA + Foxtail millet	6.07	5.96	4.56	3.79
T_8: Finger millet alone	6.33	6.07	4.42	3.79
T_9: Fodder maize alone	5.77	5.76	4.14	3.50
T_{10}: Field bean alone	6.85	6.87	5.15	4.07
T_{11}: Niger alone	5.86	5.92	4.53	3.66
T_{12}: Chilli alone	6.13	6.09	4.42	3.66
T_{13}: Cowpea alone	6.94	6.98	5.22	4.10
T_{14}: Foxtail millet alone	5.94	5.83	4.38	3.64
T_{15}: Custard apple alone	6.06	5.83	4.25	3.60
S.Em±	0.31	0.32	0.29	0.19
CD at 5 % (*p=0.05*)	0.89	0.93	0.85	NS

Depth-wise distribution of nitrogen in soil under custard apple based agri-horticulture system

Available nitrogen (N) in soil

Available N varied significantly at all depths under custard apple based agri-horticulture system (Table 7). The treatments with legume crops recorded significantly higher available N at all depths. At 0-15 cm depth, the available N was found significantly higher under CA+Cowpea (105.31 mg kg^{-1}) intercropping system. This was followed by CA+Field bean (104.70 mg kg^{-1}), cowpea alone (98.87 mg kg^{-1}) and field bean alone (98.30 mg kg^{-1}). The treatments CA+Niger (80.79 mg kg^{-1}), CA+Chilli (80.28 mg kg^{-1}), CA+Finger millet (79.57 mg kg^{-1}) and CA+Foxtail millet (77.44 mg kg^{-1}) intercropping systems were found to be on par with each other. Significantly lower available N was recorded under fodder maize alone (54.12 mg kg^{-1}) and CA+Fodder maize (62.12 mg kg^{-1}). Higher available N under leguminous crops compared to others might be attributed to their capacity to fix atmospheric N and its addition to soil after harvest of the crop. The higher content of available N on surface layers under intercropping systems is attributed to accumulation and decomposition of litterfall and greater biomass added to soil. It lead to mineralization of organic N from the litter and its release into the soil and improved available N (Baljit Singh and Sharma, 2012)[2].

Table 7: Available Nitrogen (mg kg^{-1}) distribution in soil at different depths under custard apple based agri-horticulture system

Treatments	Soil depth (cm)			
	0-15	15-30	30-60	60-90
T_1: CA + Finger millet	79.57	70.49	53.92	40.56
T_2: CA + Fodder maize	62.12	56.05	32.85	25.90
T_3: CA + Field bean	104.70	90.92	65.21	47.67
T_4: CA + Niger	80.79	75.97	49.35	36.65
T_5: CA + Chilli	80.28	67.28	51.43	40.74
T_6: CA + Cowpea	105.31	91.33	70.17	50.09
T_7: CA + Foxtail millet	77.44	71.06	48.40	42.53
T_8: Finger millet alone	71.78	63.79	47.76	36.58
T_9: Fodder maize alone	54.10	51.94	30.13	23.48
T_{10}: Field bean alone	98.30	82.63	59.04	43.70
T_{11}: Niger alone	77.14	69.72	45.48	30.38
T_{12}: Chilli alone	68.79	63.02	46.07	34.22
T_{13}: Cowpea alone	98.87	85.79	60.80	44.19
T_{14}: Foxtail millet alone	73.19	67.18	44.25	33.44
T_{15}: Custard apple alone	82.72	59.82	46.78	32.19
S.Em±	3.68	3.40	2.83	1.81
CD at 5 % (*p=0.05*)	10.67	9.84	8.19	5.24

At 15-30, 30-60 and 60-90 cm depth of soil, higher available N was recorded under CA+Cowpea (91.33, 70.13 and 50.09 mg kg^{-1}, respectively) intercropping system. Significantly lower available N was recorded under fodder maize alone (51.94, 30.13 and 23.48 mg kg^{-1}, respectively). Irrespective of the treatments, available N content in soil was decreased with increase in depth. This might be due to decreased organic matter content of the soil at lower depths since nitrogen is directly related to the organic matter content. Significant amount available N at lower depths might be attributed to leaching of soluble organic nitrogen as well as inorganic (nitrate) nitrogen from top layers and its accumulation in deeper depths of soil (Saha *et al.,* 2000) [20]. Saswati Ghosh *et al.* (2017) [22] reported that under guava + banana intercropping system the available nitrogen content of soil increased in surface soil and decreased with depth.

Total nitrogen (N) in soil

Custard apple based agri-horticulture system significantly influenced the total N content at different depths of soil (Table 8). Treatments with legume crops recorded significantly higher total N at all depths. At 0-15 cm depth, CA+Cowpea (636.65 mg kg^{-1}) intercropping system recorded significantly higher total N followed by CA+Field bean (622.48 mg kg^{-1}), cowpea alone (611.67 mg kg^{-1}) and field bean alone (605.18 mg kg^{-1}) intercropping systems. Significantly lower total N was recoded under fodder maize alone (457.25 mg kg^{-1}) cropping system followed by custard apple alone (462.12 mg kg^{-1}) and CA+Fodder maize (480.26 mg kg^{-1}) intercropping systems.

Table 8: Total Nitrogen (mg kg^{-1} of soil) distribution in soil at different depths (cm) under custard apple based agri-horticulture system

Treatments	Soil depth (cm)			
	0-15	15-30	30-60	60-90
T_1: CA + Finger millet	560.46	508.57	432.74	320.11
T_2: CA + Fodder maize	480.26	427.95	325.91	247.26
T_3: CA + Field bean	622.48	572.06	510.12	385.07
T_4: CA + Niger	532.75	489.46	424.31	302.44
T_5: CA + Chilli	515.76	476.87	399.25	272.56
T_6: CA + Cowpea	636.65	581.63	515.37	393.65
T_7: CA + Foxtail millet	548.63	495.38	416.45	321.17

T_8: Finger millet alone	532.38	479.09	388.26	253.17
T_9: Fodder maize alone	457.25	418.34	303.45	206.15
T_{10}: Field bean alone	605.18	560.25	478.23	362.75
T_{11}: Niger alone	509.33	449.19	371.12	271.48
T_{12}: Chilli alone	494.98	444.83	352.74	262.52
T_{13}: Cowpea alone	611.67	563.74	481.43	366.18
T_{14}: Foxtail millet alone	532.74	486.74	367.23	255.39
T_{15}: Custard apple alone	462.12	425.48	335.26	221.25
S.Em±	27.30	26.34	19.44	14.72
CD at 5 % ($p=0.05$)	79.09	76.30	56.30	42.64

CA+Cowpea intercropping system maintained a higher total N at 15-30, 30-60 and 60-90 cm (581.63, 515.37 and 393.65 mg kg^{-1}, respectively) depths of soil compared to other treatments and lower values were recorded under fodder maize alone (418.34, 303.45 and 206.15 mg kg^{-1}, respectively) cropping system at all three depths. Higher content of total nitrogen at surface soil (0-15 cm) might be due to presence of higher organic matter. Irrespective of the treatments, total N was decreased with increase in soil depth. The decrease in the total nitrogen content with increase in depth may be related to the close link with organic carbon and due to association of nitrogen with organic matter and adsorption of ammonical nitrogen on humus complex in the soil. Purnananda *et al.* (2017) [17] showed that soils under coconut land use system the total nitrogen content in the soils decreased with depth from 407.00 to 334.52 ppm.

Conclusion

Custard apple based agri-horticulture system significantly influenced soil properties, carbon and nitrogen distribution in soil. The intercropping systems CA+Cowpea and CA+Field bean resulted in increased carbon and nitrogen content and their forms in surface as well as in subsurface soil. Hence, inclusion of legume crops under intercropping systems proved to increase organic matter and nitrogen content of soil there by improving soil fertility. Under custard apple based intercropping system due to reduced disturbance and decreased loss of organic matter due to oxidation compared to sole crops resulted in higher organic matter conservation. This resulted better distribution of nutrients including carbon and nitrogen in the profile. So, it is concluded that practicing custard apple based intercropping system is a better option to have sustainable crop production and maintaining soil fertility.

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