LONG TERM EFFECT OF INTEGRATED NUTRIENT MANAGEMENT ON SOIL FERTILITY, POTASSIUM FRACTIONS AND YIELD OF COTTON + GREENGRAM (1:1) INTERCROPPING SYSTEM IN VERTISOLS

THESIS

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By

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DECLARATION OF STUDENT

I hereby declare that the experimental work and its interpretations of the Thesis entitled **"LONG TERM EFFECT OF INTEGRATED NUTRIENT MANAGEMENT ON SOIL FERTILITY, POTASSIUM FRACTIONS AND YIELD OF COTTON + GREENGRAM (1:1) INTERCROPPING SYSTEM IN VERTISOLS"** or part there of has neither been submitted for any other degree or diploma of any University, nor the data have been derived from any thesis / publication of any University or scientific organization. The source of materials used and all assistance received during the course of investigation have been duly acknowledged.

Place: Akola **(REGULWAR SHIVANI PRAKASH)**

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CERTIFICATE

This is to certify that thesis entitled **"LONG TERM EFFECT OF INTEGRATED NUTRIENT MANAGEMENT ON SOIL FERTILITY, POTASSIUM FRACTIONS AND YIELD OF COTTON + GREENGRAM (1:1) INTERCROPPING SYSTEM IN VERTISOLS"** submitted in partial fulfillment of the requirements for the degree of **"Master of Science in Agriculture (Soil Science and Agricultural Chemistry)"** of Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, is a record of bonafide research work carried out by **REGULWAR SHIVANI PRAKASH** under my guidance and supervision.

The subject of the thesis has been approved by the Student's Advisory Committee.

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(D) Abbreviations

%	-	per cent
/	-	Per
@	-	at the rate of
AICRP	-	All India Coordinated Research Project
BD	-	Bulk density
^0C	-	Degree Celsius
CD	-	Critical difference
cm	-	Centimeter
Cu	-	Copper
DAS	-	Days after sowing
DHA	-	Dehydrogenase activity
DTPA	-	Diethylene Triamine Penta acetic Acid
dS m^{-1}	-	Deci Siemens per meter
EC	-	Electrical conductivity
et al.	-	*et alia* (and others)
etc.	-	*Etcetera*
Fe	-	Iron
Fig	-	Figure
FYM	-	Farmyard manure
g	-	Gram
GM	-	Green manuring
GLM	-	Green leaf manure
ha^{-1}	-	per hectare
HNO_3	-	Nitric acid
H_2SO_4	-	Sulphuric acid
HCl	-	Hydrochloric acid
i.e.	-	*id est* (that is)
INM	-	Integrated nutrient management
J	-	Journal
K	-	Potassium
kg ha^{-1}	-	Kilogram per hectare

Mg	-	Megagram
mg kg^{-1}	-	Milligram per kilogram
m^2	-	Square meters
m	-	Meter
mm	-	Millimeter
Mn	-	Manganese
MOP	-	Muriate of potash
MW	-	Meteorological week
MWD	-	Mean weight diameter
N	-	Nitrogen
NS	-	Non-significant
OC	-	Organic carbon
P	-	Phosphorus
ppm	-	parts per million
PSB	-	Phosphate solublizing bacteria
q ha^{-1}	-	Quintal per hectare
RDF	-	Recommended dose of fertilizer
SSP	-	Single super phosphate
SE (m)±	-	Standard error of mean
SMBC	-	Soil microbial biomass carbon
sq.m	-	Square meter
t ha^{-1}	-	tonne per hectare
µg	-	Microgram
viz.	-	*videlicet* (namely)
yr^{-1}	-	per year
Zn	-	Zinc

(E) THESIS ABSTRACT

a.	Title of the thesis	:	**LONG TERM EFFECT OF INTEGRATED NUTRIENT MANAGEMENT ON SOIL FERTILITY, POTASSIUM FRACTIONS AND YIELD OF COTTON + GREENGRAM (1:1) INTERCROPPING SYSTEM IN VERTISOLS**
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ABSTRACT

A field study entitled, “Long term effect of integrated nutrient management on soil fertility, potassium fractions and yield of cotton + greengram (1:1) intercropping system in Vertisols” was conducted during

kharif 2019-20 at Research field of AICRP for Dryland Agriculture, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra. The soil of the experimental site was Vertisol which was moderately alkaline in reaction, low in available nitrogen, medium in available phosphorus and high in available potassium.

The eight treatments replicated three times in randomized block design comprised of control, 50% and 100% RDF, 50% N ha^{-1} through gliricidia / FYM, 50% N through fertilizers + 50% N ha^{-1} through gliricidia / FYM + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers, 100% N ha^{-1} through gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} through fertilizers.

The results after 33rd cycle indicated that application of 50% RDN through FYM in combination with 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through fertilizers recorded higher cotton + greengram yield and was on par with the application of 50% N through gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through fertilizers and application of 100% RDF. However, the significant improvement in soil fertility and potassium fractions was recorded with application of 50% N through gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through fertilizers and was on par with 50% RDN through FYM in combination with 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through fertilizers. Among the various potassium fractions, the exchangeable and lattice K was highly correlated with yield of crops.

Hence, it is concluded that the integrated application of 50% N through gliricidia / FYM + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through fertilizers resulted in improvement in soil fertility, potassium fractions and yield of cotton + greengram (1:1) intercropping system in Vertisols under rainfed conditions.

CHAPTER I

INTRODUCTION

1.1 Background information

Cotton (*Gossypium spp*.) is the most important fibre crop originated in India and belongs to Malvaceae family. It is backbone of our textile industry, accounting for 70 per cent of total fibre consumption in textile sector. Among different species of cotton *Gossypium hirsutum* and *Gossypium arboreum* are commonly grown in Maharashtra and used in textile industries for manufacture of cloth. The cotton is mostly grown on black cotton soils, the typical swell-shrink soils of Deccan Plateau.

World cotton area and production in 2019-20 is estimated at 33.4 million hectares and 118.6 million bales. India is the largest cotton growing country in the world and occupies 37.5% world cotton area and produces around 24.3% of world cotton production. In 2019-20 area, production and productivity under cotton in India is estimated as 125.84 lakh ha, 360.0 lakh bales of 170 kg and 486 kg ha^{-1} respectively. In India, Maharashtra rank first in acreages with 43.69 lakh ha and 82.0 lakh bales production with average productivity of 319 kg lint/ha (Anonymous,2019 -20a).

In Maharashtra state, Vidarbha is the largest cotton growing region accounting for 15.81 lakh ha^{-1} acreage with production of 35.5 lakh bales and productivity of 388.0 kg lint ha^{-1} (Anonymous, 2019 -20b).

Greengram (*Vigna radiata*) is popularly known as “moong dal” and one of the main pulse crop in India. It contains 20-25% protein and is a rich source of low fat protein, has a wide amino acid profile and contains no trans and saturated fats. It is cultivated in variety of soils from red lateritic to black cotton soil. More than 70 % of world’s greengram production comes from India. It also plays an important role in maintaining and improving the fertility of soil through its ability to fix atmospheric nitrogen in the soil by root nodules. It is good green manure and erosion resisting cover crop.

In India, the area under greengram is about 34.4 lakh ha with production of 14.00 lakh tonnes and productivity of 406.98 kg ha^{-1} whereas, Maharashtra has about 4.8 lakh ha area with production of 2.0 lakh tonnes and productivity of 423.6 kg ha^{-1}. The area under greengram in Vidarbha is 0.83 lakh ha and production of 0.44 lakh tones with productivity of 333.0 kg ha^{-1} (Anonymous, 2019 -20b).

Potassium (K) is the essential macronutrient for all living organisms required in large amounts for normal plant growth and development (Marschner, 1986). It's deficiencies can limit the accumulation of crop biomass. This is attributed to fact that K increases the photosynthetic rates of crop leaves, CO_2 assimilation and facilitates carbon movement.

Potassium is considered second only to nitrogen, when it comes to nutrients needed by plants and is commonly considered as the "quality nutrient". It affects the plant shape, size, colour, taste and other measurements attributed to healthy produce. It plays a major role in the regulation of water in plants (osmoregulation). Both uptake of water through plant roots and its loss through the stomata are affected as well as it improves drought resistance. In starch synthesis, the enzyme responsible for the process is activated by potassium.

Gliricidia sepium plant belongs to leguminous family with subfamily Papilionoideae. It is a leguminous multipurpose tree and adopts very well in a wide range of soils. The green leaves of gliricidia decompose relatively fast, providing nitrogen and potassium and plays important role in increasing the fertility status of soil and helps in conserving soil through reduced soil erosion also. Patil (1989) stated that 1 tonne dry weight of leaves was equivalent to 27 kg N while Kang and Mulongoy (1987) reported that up to 15 t/ha/year of gliricidia leaf biomass could be produced on good soils in Nigeria providing the equivalent of 40 kg N/ha/year.

Integrated nutrient management is the process to maintain the soil fertility and plant nutrient supply at an optimum level through optimization by the benefits of all possible sources of nutrients like inorganic, organic, bio-fertilizers and through green manure. It enhances the availability of applied

as well as native soil nutrients, synchronizes the nutrient demand of the crop with nutrient supply from native and applied sources and improves the physical, chemical and biological functioning of soil.

In view of the facts stated above, the present study was carried out to study long term effect of integrated nutrient management on soil fertility, potassium fractions and yield of cotton + greengram (1:1) intercropping system in Vertisols.

1.2 Importance and need of study

Cotton is a major cash crop of India. It sustains the Indian cotton textile industry, which constitutes the single largest segment of organised industries in the country.

Recent studies have revealed that continuous use of suboptimal doses of nutrients in the intensive cropping system has led to severe depletion of nutrient reserves in soil, causing multiple nutrient deficiencies. The use of high-analysis fertilizers devoid of micronutrients has also aggravated micronutrient deficiencies causing significant decline in crop productivity. No single dose of plant nutrient applied through chemical fertilizers, organic manures, crop residues or bio-fertilizers can meet the entire nutrient need of a crop in modern intensive agriculture. Rather, these need to be used in an integrated manner following a management technology which is practicable, economically viable, socially acceptable and ecologically sound (Mahajan and Gupta, 2009).

There is now tremendous pressure on growers to use integrated nutrient management approach to increase productivity and sustain soil health. Organic amendment offers an alternative or supplementing control tactic to increase production (Meena *et al*., 2015).

INM regulates nutrient supply for optimum crop growth and higher productivity. It improves and maintain of soil fertility. It has zero adverse impact on agro-ecosystem quality by balanced fertilization of organic manures, inorganic fertilizers and bio-inoculants.

Most of the black soils were thought to be well supplied with K and thus, it was presumed that they do not need K application. However, in

view of potential of newly released high yielding varieties of crops these soils may not be well supplied with K. In view of the high potassium content in swell shrink soils it was not the general practice to recommend potassium, like regular application of N and P fertilizers. Among the major nutrients, potassium not only improves yields but also benefits various aspects of quality. Although the potassium content of Vertisols and associated intergrades is high, many crops have been found to give good response to application of potassium. Most crops absorb as much or more K than they absorb N from the soil. The nutrient removal exceeds nutrient addition. Potash balance in Maharashtra is negative and mining of soil K reserves is going on at an alarming pace (Kadam *et al*., 2016).

1.3 Objectives

The study on "long term effect of integrated nutrient management on soil fertility, potassium fractions and yield of cotton + greengram (1:1) intercropping system in Vertisols" was planned with the following objectives:

1. To study the long term effect of integrated nutrient management on potassium fractions in soil.
2. To assess the long term effect of integrated nutrient management on soil fertility and yield of cotton + greengram (1:1) intercropping system.
3. To study the relationship of different potassium fractions with yield of cotton + greengram (1:1) intercropping system.

1.4 Scope and limitation

Soil K exists in four different forms *viz.*, soil solution K, exchangeable K, non-exchangeable K and mineral K. Major portion of soil K exists as constituent of mineral structure and in fixed or non-exchangeable forms with minor portion as water soluble and exchangeable K. Different forms of K are correlated with each other indicating that dynamic equilibrium is maintained among these forms. Due to the dynamic equilibrium between different forms, depletion in the given form of K is likely to shift the equilibrium in the direction to replenish it. These equilibrium reactions affect the level of soluble potassium at any time and accordingly, the amount of potassium

available for plants. Potassium availability to plants, in general, is governed by these different forms of K *viz.,* water soluble K, exchangeable K, fixed K and mineral K.

Potassium plays several roles in plants such as enzyme activation, protein synthesis, ion absorption and transport, photosynthesis and respiration. Among the major nutrient elements, K is usually the most abundant in soil. Its amount in soils varies depending on parent material, degree of weathering, gains through fertilizers and losses through crop removal, erosion and leaching. A major consequence of decline on soil fertility in agriculture land is the greater prevalence of sustained period of moisture deficiency resulting from poorer water storage throughout the soil profile. The increasing events of moisture and other abiotic stresses arising from loss of soil fertility as well as from global warming will necessitate a specifically high supply of potassium for stress mitigation. The inadequate recycling of potassium in Indian agriculture thus puts these soils and the crops they carry at risk.

Potassium is one of the three main pillars of balanced fertilizer use, along with nitrogen (N) and phosphorus (P). It is associated with movement of water, nutrients and carbohydrates in plant tissue, also stimulates early growth, improves the efficiency of water use, is vital for stand persistence, longevity, and improves resistance to diseases and insects. If K is deficient or not supplied in adequate amounts, growth is stunted and yields are reduced.

Long term studies are the basic platform for examination and quantification of cultivation and the evaluation of effects of continuous fertilizer application on different nutrient dynamics in soil. The potassium release rates from soil under long-term cropping, fertilizer application and manuring helps to predict the fate of added K in soil as well as nature of K supply from soil to plant. Several studies have shown that intensive cropping systems may cause heavy depletion of soil potassium under long-term experiments. Potassium as a macronutrient is often taken up in large quantities by crops under intensive

cropping and its uptake in many crops is almost equal to nitrogen. Long-term

fertilizer experiments provide the means for studying changes in crop productivity and soil fertility under given level of input use and management practices over a period of time.

1.5 Hypothesis

The integrated nutrient management envisages the use of chemical fertilizers in conjunction with organic manures, legumes in cropping system, bio-fertilizers and other locally available nutrient sources for sustaining soil health.

The long-term fertilizer experiments are precious assets to access the impact of crop management on soil health and *vice-versa*, and also to forewarn against management-induced soil problem. These experiments can be used for precise monitoring of changes in soil fertility and productivity.

Potassium has specific role in creating drought resistance in crops and known to improve the water use efficiency which can be very beneficial in with standing drought stress in crops especially in prolonged dry spells. It has also been established that potassium helps in inducing pest and disease resistance in plants.

Increasing incidences of potassium deficiencies coupled with the need to fertilize responsibly to avoid environmental and animal health consequences, demonstrate that we need a better understanding of K dynamics in soil, plants and animals in agricultural system. Potassium fertilization is indispensible for Indian agriculture. However, with increasing cost of potassic fertilizers and unsure returns from this costly input, farmers are often inclined not to use K or to replace K with N or P fertilizers. The information regarding distribution of different fractions of K in relation to soil properties under integrated nutrient management is useful to understand the capacity of soil to supply K to the plants. Also, this study will help for better understanding of different potassium fractions and its effect on yield of crop and soil fertility.

CHAPTER II

REVIEW OF LITERATURE

In this chapter, it has been attempted to summarize a brief review of the work done in respect of the project entitled “Long term effect of integrated nutrient management on soil fertility, potassium fractions and yield of cotton + greengram (1:1) intercropping system in Vertisols”. The literature pertaining to the present study has been briefly reviewed under the following heads.

2.1. Effect of integrated nutrient management on soil fertility and yield of crops

2.2. Effect of integrated nutrient management on potassium fractions in soil

2.3. Relationship of different potassium fractions with yield of crops

2.4. Correlation studies of potassium fractions

2.1. Effect of integrated nutrient management on soil fertility and yield of crops

Babhulkar *et al*. (2000) studied residual effect of long term application of FYM and fertilizers on soil properties and reported that, increase in available zinc content, OC, total nitrogen, available phosphorus and available potassium were higher under use of 15:30 NP + 7.5 t FYM ha^{-1} after harvest of soybean crop. It might be due to addition of FYM which help to stimulate the growth and activity of micro organisms. This effect was further enhanced by addition of N and P resulting in improvement in root and shoot growth. Higher production of biomass might have increased the organic carbon content.

Basavanneppa and Biradar (2002) found that the application of FYM @ 10 t ha^{-1} recorded highest seed cotton yield over incorporation of cotton crop residue @ 5 t ha^{-1} and vermicompost 2.5 t ha^{-1}. Further, cotton and maize yields were increased with every increment in the levels of RDF.

Katkar *et al.* (2002) reported that recommended dose of fertilizer recorded highest seed cotton yield followed by the treatment

receiving 50 per cent RDF + 5 t FYM ha^{-1}. Among the organic treatments, the application of FYM alone, mulching, glyricidia green foliage lopping and sunhemp green manuring recorded increase in seed cotton yield over control.

Ismail *et al*. (2002) reported significant build up in Fe, Zn, Mn and Cu in Vertisols in the treatment receiving 50 % RDF + 5 Mg FYM ha^{-1} as compared to application of RDF or FYM alone, whereas depletion of the micro nutrient content was noticed in control.

Duhan and Singh (2002) noticed that the yield and micronutrients (Zn, Fe, Mn, Cu) uptake by rice increased with sunhemp green manured plot followed by greengram.

Solaiappan (2002) conducted a field experiment for four consecutive years on Vertisols and revealed that, application of recommended dose of inorganic fertilizers and FYM @ 25 t ha^{-1} once in two years recorded higher cotton yields, followed by the application of RDF + FYM @ 12.5 t ha^{-1} as compared to organics or inorganic fertilizers.

Thind *et al.* (2002) studied the effect of different organic amendments and different nitrogen levels on yield, nitrogen uptake and nutrient status under maize-wheat rotation and observed that the residual effect of organic manures on succeeding wheat yield was higher in FYM treated plots, followed by dhaincha, moong, guar and cowpea treated plots. Organic carbon, available N, P and K contents of soil were greater in FYM treated plots than plots treated with green manure.

Tolanur and Badanur (2003) conducted a field experiment to study the effect of inorganic fertilizers coupled with organic manure and green manure on organic carbon, available N, P and K in Inceptisol and observed that organic carbon content of surface soil increased significantly with incorporation of FYM or subabul in conjunction with fertilizer.

Blaise *et al.* (2003) reported that at the end of eight cycles of cotton- sorghum rotation, seed cotton yield was enhanced in the NPK + FYM plots compared to NPK alone plots.

Selvi *et al.* (2003) studied a long-term experiment conducted since 1972 on Vertic Ustropept which indicated that application of 10 t ha^{-1} of FYM along with 100 per cent NPK recorded increase in CEC, organic carbon and total N content of soil due to incorporation of organics with inorganics. There was no marked change in soil pH and EC due to various treatments. Available micronutrients and major nutrients increased significantly when organics were incorporated along with inorganic sources of nutrients.

Halemani *et al*. (2004) noticed that application of FYM @ 10 t ha^{-1} to cotton increased carbon content, soil available nitrogen, P_2O_5 and K_2O as compared to control.

Singh *et al.* (2004) reported that application of FYM 10 t ha^{-1} along with recommended dose of fertilizers and crop rotation significantly increased the productivity (26%), soil organic carbon (31%), Zn (33.3%), Fe (24.4%) and Mn (6%) as compared to control.

Nehra *et al*. (2004) conducted a field experiment to evaluate the integrated effect of organic and inorganic fertilizer management on the production of *hirsutum* cotton during 2001-2002 and 2002-2003 and the pooled mean data indicated that 50% NPK + 10 t FYM ha^{-1} + foliar nutrition recorded the highest seed cotton yield and remained statistically at par with 100% NPK + 5 t FYM ha^{-1}, 50% NPK + 10 t FYM ha^{-1} and 100% NPK + 10 t FYM ha^{-1}. The highest number of bolls $plant^{-1}$, higher boll weight and plant height were also recorded by the same treatment.

Praharaj *et al.* (2004) studied various crop residue application alone and in combination with FYM in cotton and recorded higher availability of nitrogen with the application of FYM @ 10 t ha^{-1} followed by FYM @ 5 t ha^{-1} + crop residue @ 5 t ha^{-1} and FYM + GM as compared to chemical fertilizers as well as control.

Raskar (2004) conducted a field experiment on fine clay soil at Rahuri and reported that application of 100 per cent RDF + green manure to cotton was found to be optimum, which recorded significantly more cotton yield over 50 and 75 per cent RDF and without green manuring.

Kamble *et al*. (2005) worked on effect of *in-situ* green manuring and nitrogen levels in hybrid cotton under transitional tract of Dharwad on black clay loam soil and observed that lucerne green manuring recorded significantly higher seed cotton yield over all other green manuring crops. Lucerne green manuring with 100 % RDF recorded significantly higher seed cotton yield.

Blaise *et al*. (2005) conducted an experiment on nutrient uptake and balance of the cotton + pigeonpea, a traditional strip intercropping system practiced on the rainfed Vertisols and concluded that the nutrient uptake, in general, was higher on deep soil than on medium deep soils. Among the interventions, N, P and K uptake of cotton and pigeonpea followed the order: application of $ZnSO_4$ > conservation tillage with *in-situ* green manure > RDF > farmer's practice (FP). Mean N and P balance was positive in all the treatments. The balance may become negative if nutrient losses are accounted. A negative K balance was observed in all the treatments and the magnitude was the greatest for the FP plots. In spite of fertilizer-K application in the intervention plots, K balance was negative.

Deshmukh *et al.* (2005) evaluated that 100% recommended fertilizer dose (N_{20}, P_{40} + K_{25} kg $ZnSO_4$/ha) + 2.5 tonnes FYM/ha + drainage in soybean and soil mulch in chickpea proved the best in growth, yield attributes, yield and economics from soybean and chickpea and increasing the fertility status of the soil.

Mahavishanan *et al.* (2005) studied the effect of INM in cotton-sunflower cropping system and indicated that highest yield and NPK uptake was observed with combined application of FYM 12 t ha^{-1}, green manure and 50 per cent RDF in sandy loam soil.

Katkar *et al.* (2006) revealed that maximum seed cotton yield was recorded by the treatment of FYM @ 5 t ha^{-1} + 50% RDF followed by glyricidia green foliage lopping at 30 DAE @ 5 t ha^{-1} + 50 % RDF and 100% RDF, and statistically similar NPK uptake in the treatment 100% RDF, FYM 5 t ha^{-1} + 50% RDF and gliricidia + green foliage lopping @ 5 t ha^{-1} + 50% RDF.

Bhoite and Thombre (2006) studied various components of integrated nutrient management in irrigated cotton at Rahuri and observed that the seed cotton yield was significantly higher with 100% RDF + FYM @ 10 t/ha which was at par with 50% RDF + intercropping of sunhemp for *in-situ* green manure. The number of bolls per plant and 100 seed weight was maximum in 100% RDF + FYM @ 10 t/ha which was at par with 50% RDF + intercropping of sunhemp for *in-situ* green manure. Seed cotton weight per boll was maximum in the treatment 50% RDF + FYM @ 10 t/ha + foliar spray of 2 per cent urea + 2 per cent DAP at boll development. 50% reduction in RDF may possible without decreasing seed cotton yield significantly with the treatment 50% RDF+ intercropping of sunhemp for *in-situ* green manuring.

Laxminarayan and Pritam (2006) worked on the effect of integrated use of inorganic fertilizers coupled with organic manures, green manures and phosphate solubilising bacteria on yield, nutrient uptake of rice and their residual effect on soil fertility in an Ultisol of Mizoram and concluded that application of optimum doses of NPK in combination with green manure @ 5 Mg ha^{-1} recorded highest grain and straw yield.

Khan *et al.* (2007) reported that the combined application of NPK + organic manures (GM or FYM) + Zn significantly increased the paddy and straw yields of rice crop. Integrated fertilization also had pronounced residual effects on grain and straw yields of wheat. The results showed that organic manures especially NPK + FYM had direct and residual effects on both rice and wheat yields.

Pothare *et al.* (2007) studied the long-term fertilizer experiment started since 1988 at Dr. PDKV, Akola and reported that all the soil chemical properties such as pH, EC, organic carbon, total and available NPK and S were favourably influenced with the conjunctive use of organic and inorganics. Highest improvements were observed in the treatment of 100% NPK + 10 t FYM ha^{-1}.

Mweta *et al.* (2007) studied the effect of green manure pruning and mineral fertilizer on yield, phosphorus adsorption and uptake by maize crop in a gliricidia-maize intercropping at Malawi. The results indicate that addition of gliricidia pruning increased P availability through reduced P

sorption capacity of the soil and recycling of P. Combination of gliricidia pruning and inorganic P fertilizer has an added benefit compared to application of either gliricidia pruning or inorganic P fertilizer alone.

Devraj *et al.* (2008) reported that the highest seed cotton yield was obtained where 50 per cent recommended dose of NPK + 10 t FYM ha^{-1} + foliar spray of urea (2 per cent) were applied. Effect of recommended dose of NP on seed cotton yield was on par with recommended dose of NPK.

Kide *et al.* (2008) conducted experiment on Typic Haplusterts and results revealed that different organic sources like gliricidia in combination with recommended dose of fertilizers influenced the seed cotton and dry matter yield of cotton.

Kaur *et al.* (2008) studied the pooled data of three years (2004-2006) and revealed that the significantly higher seed cotton yield of 2437 kg ha^{-1} was obtained with the integration of 10 t FYM ha^{-1} and foliar sprays of KNO_3 with 50 per cent of the recommended dose of NPK fertilizers as compared to all other treatments.

Kumar *et al.* (2008) conducted a long-term field experiment on integrated management of FYM, green manure and crop residues with inorganic fertilizers in rice-wheat system at Ludhiana, since 1993. They reported that long-term application of crop residues and organic manures significantly reduced the soil pH and EC and increased the soil organic carbon content and yield of crop.

Vaiyapuri *et al.* (2008) conducted experiment at Tamilnadu and observed that green manuring significantly improved the soil physical and physico-chemical properties *viz.*, organic carbon, total and available nitrogen, available phosphorus, available potassium contents and water holding capacity of the soil over control.

Desai *et al.* (2009) reported that application of crop residues and FYM improved available P and K in soil in organic treatments as compared to treatments where chemical fertilizers were applied.

Garrido *et al.* (2009) observed that the treatment with gliricidia incorporation resulted in greater soil N availability, greater accumulation of

nutrients in the dry biomass of the crop and greater apparent recovery of N, P and K, relative to the other treatments and stated that manure did not increase soil N availability, but the mixture of manure and gliricidia increased availability of soil N, P and K in relation to the control treatment, proving to be a promising practice capable of improving the quality of animal manure, while working on the growth and uptake of nutrients by cotton fertilized with gliricidia and/or manure at Brazil.

Kamble *et al.* (2009) conducted a field trial on a black clay loam soil at Karnataka and observed that application of leucaena green manuring with 100 per cent recommended dose of nitrogen recorded significantly higher dry matter yield and seed cotton yield over all other treatment combinations.

Shirale and Khating (2009) studied the effect of organic and inorganic nutrients on yield and nutrient balance in different cropping systems in Vertisol at Parbhani and observed that the highest total grain yield was recorded by RDF followed by gliricidia @ 1.5 t ha^{-1} + 25% RDF and it was at par with each other. There was more build up of available N, P and K in soil with soybean + pigeonpea cropping system with FYM followed by gliricidia.

Jayakumar *et al.* (2009) conducted a field experiment in cotton to evaluate the effect of intercropping and sources of nitrogen involving organic and inorganic sources. The experimental results revealed that cotton + blackgram intercropping with 75% inorganic N + 25% N through poultry manure recorded lower weed density, higher cotton yield, cotton equivalent yield, better economics and higher post harvest nutrient status.

Mehta *et al.* (2009) observed maximum N and P content in cotton seed and statistically higher seed cotton yield, where 100% recommended dose of fertilizer through chemical fertilizer were applied. Similarly higher nitrogen uptake and phosphorus uptake by cotton was observed in this treatment over control and rest of organic and inorganic combination treatment.

Praharaj *et al.* (2009) worked on the sustaining cotton productivity and soil fertility through *in-situ* management of green manure and crop residues in semi-arid irrigated condition of Coimbatore and noticed that the simultaneous planting of sunhemp and cotton under ridge-furrow system, followed by burying of sunhemp @ 2.5 t/ha *in-situ* before flowering followed by earthing up was optimum for higher cotton productivity, net return and B:C ratio.

Rao and Janawade (2009) conducted a field experiment to study the effect of green manure, organic manure and fertilizers on changes in physical and chemical properties of a medium black soil. The results indicated that physical parameters *viz.*, bulk density and infiltration rate of soil were favourably affected by either green manures or organic manures application. Green manuring with sunhemp which appeared better, decreased the bulk density of soil as compared to control. Combination of green manure, organic manure and chemical fertilizer showed higher improvement in soil physical and chemical properties as compared to application of organics and inorganics alone.

Regar *et al*. (2009) conducted experiment in arid and semiarid regions at Rajasthan and observed that incorporation of crop residues of mustard and taramira (*Eruca vesicaria*) straw at 5 t ha^{-1} and with equal amount of FYM and green manuring with dhaincha (*Sesbania aculeata*) improved the soil organic carbon, available nitrogen, phosphorus and yield of crop.

Bandyopadhyay *et al.* (2010) reported that the that conjunctive use of recommended dose of fertilizer and farmyard manure (NPK + FYM) resulted in significant decrease of bulk density, soil penetration resistance and increase in hydraulic conductivity and mean weight diameter of the water stable aggregates and soil organic carbon content compared to control. Among the aggregates, in macroaggregate fraction and in large macro-aggregate fraction maximum soil organic carbon concentration was recorded under NPK + FYM.

Gayatri *et al*. (2010) conducted a study to understand the effect of integrated nutrient management on soil properties; soil samples were

drawn from the AICRP on long-term field experiment (LTFE) in progress since kharif, 1997 on a Typic Haplustept at Udiapur. The rotation followed was maize-wheat and the treatments included various combinations of N, P, K, Zn, S, *azotobacter* and FYM. Application of 20 t FYM ha^{-1} and combined use of NPK and 10 t FYM ha^{-1} recorded significant differences in the physico-chemical properties of the soil *viz*., bulk density, hydraulic conductivity, electrical conductivity and cation exchange capacity. However, no marked changes in soil pH over the years were noticed.

Lalithakumari *et al*. (2010) conducted a long-term experiment to study the effect of different manures and fertilizers on productivity and soil fertility of rainfed cotton and noticed that the pooled mean yield of cotton was highest in the treatment that received 100 per cent NPK + FYM 10 t ha^{-1} followed by 150 per cent NPK, while the quality parameters were not affected significantly.

Nawlakhe and Mankar (2010) reported that 25 kg N through fertilizer + 25 kg N through FYM + 25 kg P_2O_5 treatment recorded maximum total dry matter accumulation of cotton and greengram. The same treatment also proved to be the best in respect of yield of cotton as well as greengram under cotton + greengram intercropping followed by 50 kg N+ 25 kg P_2O_5 ha^{-1} through inorganic fertilizer *i.e.* 100 % RDF treatment.

Kumar and Singh (2010) studied long-term effect of green manuring and farmyard manure on yield and soil fertility status in rice-wheat cropping system at Pusa, Bihar and observed that combined application of 100% NPK + 5.0 t FYM each year gave significantly higher available N, P, K and higher content of DTPA-extractable Zn, Fe, Mn and Cu in post-harvest soil at the end of six years cycle. It was concluded that integrated application of 100% NPK + 5.0 t FYM was the most effective treatment in meeting the micronutrient requirements of rice and wheat crops.

Deshmukh *et al.* (2011) observed increasing trend in yield of Bt cotton with increase in FYM and similar trend was also observed with respect to N,P and K uptake by Bt. Cotton, from the experiment on yield and nutrient uptake of *kharif* Bt. cotton as influenced by conjoint use of FYM and chemical fertilizer.

Nandapure *et al.* (2011) revealed that the combined use of inorganic fertilizers (100 % NPK) along with FYM @ 10 t ha^{-1} significantly improved the bulk density, hydraulic conductivity, available water capacity, water stable aggregates and coefficient of linear extensibility of soil and yield of crops. Total productivity (sorghum + wheat) was found to be positively correlated with these properties.

Sharma *et al*. (2011) carried out soil quality assessment study on long-term experiment from Akola Centre (Maharashtra) of All India Coordinated Research Project for Dryland Agriculture (AICRPDA) and reported that 25 kg P_2O_5 ha^{-1} + 50 kg N ha^{-1} through *leuceana* showed the greatest organic C content, followed by 25 kg N + 25 kg P_2O_5 ha^{-1} + 25 kg N ha^{-1} through FYM.

Solunke *et al*. (2011) revealed that the significantly maximum number of bolls, boll weight and seed cotton yield were recorded in treatment combinations of FYM @ 10 t ha^{-1} + 50:25:25 kg NPK ha^{-1} and vermicompost @ 2 t ha^{-1} + 50:25:25 kg NPK ha^{-1} over remaining treatments of organic and inorganic sources of nutrients.

Thakur *et al.* (2011) conducted a field experiment on medium black soil (Vertisols) to show the effect of conjoint use of inorganics and organic manures and observed that the use of organic manures along with 100% NPK not only sustained the higher yield of soybean but also improved the soil fertility.

Vidyavathi *et al*. (2011) worked on influence of nutrient management practices on crop response and economics in different cropping systems in a Vertisol at Dharwad and reported that integrated application of manure and fertilizers resulted in significantly higher available N, P_2O_5, K_2O and S than chemical fertilizers alone. Significantly higher uptake of N, P and K by *kharif* and *rabi* crops was recorded in integrated practice compared to inorganic nutrient management practice.

Shah and Sisodia (2012) found that application of FYM @ 10 t ha^{-1} along with recommended dose of NPK recorded the highest seed cotton yield during all the three successive years of experimentation. The treatment

100% NPK + FYM 10 t ha^{-1} exceeded all other treatments and was found superior in respect of grain and straw yields of wheat and at par with treatment 150% NPK.

Singh *et al.* (2012) reported that application of FYM @ 5 t ha^{-1} increased organic carbon, available N, P and K contents and biological properties of soil as well as yield of component crops and pigeon pea equivalent over no FYM application.

Sonune *et al*. (2012) conducted a field experiment during 2005-06 to 2007-08 and revealed that the conjunctive use of 15 t FYM ha^{-1} along with 50% RDF recorded significantly highest seed cotton yield. However, the integrated application of 10 t FYM ha^{-1} along with 50% RDF also found beneficial in sustaining the seed cotton yield with improvement in physical, chemical and microbial properties of Vertisols.

Gabhane *et al.* (2013) reported significantly highest yield of cotton and greengram with build up of soil fertility and maximum economic returns with long term application of 25 kg N and 25 kg P_2O_5 ha^{-1} through urea and SSP and 25 kg N ha^{-1} through FYM in Vertisols under dryland agriculture.

Singh *et al.* (2013) worked on interactive effect of moisture conservation and integrated nutrient management on yield and nutrient utilization efficiency of rainfed Bt cotton (*Gossypium hirsutum*). Results of three years revealed that the intercropping system in Bt cotton hybrid with greengram (*Phaseolus radiatus*) enhanced the seed cotton as well as seed cotton equivalent yield significantly over sole cotton. Higher seed cotton equivalent yield was also recorded with cotton intercropped with greengram followed by *in-situ* mulching of sunnhemp (*Crotolaria juncea*) and opening of furrows in alternate row of cotton as compared to conventional method.

Tamboli *et al*. (2013) conducted a field experiment to know the response of *rabi* sorghum to Zn as limiting nutrient on Inceptisol under dryland condition at Zonal Agricultural Research Station, Solapur during the *rabi* season 2007-08 to 2011-12 and reported that maximum values of organic carbon was recorded under FYM @ 5 tha^{-1} + recommended dose of

fertilizer (50 kg N + 25 kg P_2O_5 ha^{-1} + Zn @ 10 kg ha^{-1} as $ZnSO_4$).

Gabhane *et al.* (2014) reported that the integrated application of FYM @ 10 t/ha along with 50% RDF was beneficial in improving soil quality and sustaining the rainfed cotton productivity in Vertisols under semi-arid conditions of Maharashtra.

Ramachandrappa *et al*. (2014) conducted a field experiment at Bangalore under rainfed situation on deep, yellowish red, sandy loam soils to study the response of finger millet to the application of different grades and time of application of potassium and indicated that application of FYM or *Gliricidia sepium* registered significantly lower grain yield compared to application to 150 % of recommended K.

Marimuthu *et al.* (2014) conducted a study on cotton to evaluate the different cotton based intercropping system along with balanced nutrient management practices on enhancing cotton productivity and concluded that cotton intercropped with dhaincha recorded highest yield and uptake of N, P, and K. Among the nutrient management practices, application of 100% recommended NPK with bio-inoculants showed highest uptake of N, P and K. A similar trend was noticed in the post harvest soil fertility too.

Channagouda *et al.* (2015) worked on performance of cotton under organic production system and the results revealed that combined application of compost (50%) + vermicompost (50%) equivalent to RDF + green leaf manure as mulch with application of jeevamrutha @ 500 L/ha recorded higher cotton yield and it was superior over RDF alone. Combined application of crop residue (50%) + vermicompost (50%) equivalent to RDN with lucerne with jeevamrutha @ 500 L/ha surface application recorded significantly higher net returns over other combinations.

Doli *et al.* (2015) conducted an experiment on effect of fertility levels and green manuring on *Bt* cotton and observed that the seed cotton yield was influenced significantly due to different green manuring treatments *i.e.* green manuring with sunhemp recorded significantly more yield over treatment green manuring with cowpea.

Gudadhe *et al.* (2015) studied the effect of organic and inorganic fertilizers on crop yield and soil physical, chemical and biological properties in the cotton-chickpea cropping sequence and reported that the application of RDF according to Soil Test Crop Response (STCR) equation recorded significantly higher seed cotton yield and cotton equivalent yield, however it was at par with 10 t FYM ha^{-1} + RDF. Chickpea registered significantly higher seed yield in 10 t FYM ha^{-1} + RDF and it was at par with 100% RDN through vermicompost. 100% RDF registered significantly superior chickpea seed yield and cotton equivalent yield. The soil physical, chemical and biological properties determined at the end of two crop cycles were improved due to the application of manures in sole or in combination with chemical fertilizers.

Naik (2016) reported that the conjunctive application of 100% NP + 10 kg N (inorganic) + 20 kg K ha^{-1} through gliricidia green leaf manuring at 30 DAS resulted in improvement in soil fertility, soil health, nutrient uptake and yield of cotton grown in Vertisols under rainfed conditions.

Simon *et al.* (2016) conducted field experiment on growth and yield response of cotton (*Gossypium hirsutum*) to inorganic and organic fertilizers in southern Malawi and observed that the use of gliricidia biomass with inorganic fertilizer improved cotton yields. The high amount of gliricidia biomass (due to prolific coppicing) applied contributed to higher cotton lint yields with reduced rates of inorganic fertilizer application, making gliricidia-cotton intercropping a cost-effective option to farmers.

Dhakal *et al.* (2016) carried out a field experiment to study the influence of integrated nutrient management on greengram [*Vigna radiata*(L.)] and reported that among different combinations, significant improvement in number of nodules/plant, dry weight of nodules, yield attributes, seed yield, harvest index, nutrient content, available NPK and organic carbon after harvest in soil were recorded with application of nutrients through 75% RDF + 2.5 t/ha vermicompost + *rhizobium* + Phosphate solubilizing bacteria (PSB) as compared to other combinations and control, but it was at par with 100% RDF + 2.5 t/ha vermicompost and

100% RDF + *rhizobium* + PSB.

Meena *et al.* (2016) worked on effect of integrated nutrient management on growth and yield of greengram and noticed that growth and yield of greengram in treatment $N_{20}P_{40}K_{40}$ + FYM @ 10 t ha^{-1} and *Rhizobium* was maximum. Maximum plant height, number of leaves $plant^{-1}$, number of branches $plant^{-1}$ (at 60 DAS), number of cluster $plant^{-1}$,number of pods $plant^{-1}$ and total seed yield (q ha^{-1}) were found to be significant over all other treatments. Adequate plant nutrient supply holds the key for improving the growth and food grain production of crop.

Dakuo *et al.* (2016) conducted experiment to determine potassium fertilization efficacy on three soil types. Results showed that available K contents of Cambisol were higher than those of Ferralsol and Lixisol which had low soil organic matter contents. Compared to the control plot (no application of K_2O), K fertilization improved potassium nutrition indexes (IK) of cotton with better efficacy of applied doses on Cambisol and Lixisol. Potassium doses effects on crop yields showed the best response on seed cotton yield by Ferralsol, at the first year of application. Additional K fertilizers supplied by 60 kg/ha K_2O on the three soil types appeared to be necessary for increasing crop productivity.

Ranpariya *et al.* (2016) conducted a field experiment during summer season of 2016 at the instructional farm, Junagadh Agriculture University, Junagadh. The application of potassium, zinc and FYM significantly increased the growth attributes, quality and yield of greengram. The results revealed that the higher values of growth attributes and yield of greengram was obtained under the application of potassium @ 60 kg ha^{-1}, zinc sulphate @ 10 kg ha^{-1} and FYM @ 5 t ha^{-1} than other treatments. The quality parameters like protein content and protein yield significantly increased with the application of potassium @ 40 kg ha^{-1} and zinc sulphate @ 10 kg ha^{-1}.

Wagh *et al.* (2016) studied the effect of INM on soil quality and cotton productivity under different tillage practices in Vertisols and observed that the seed cotton yield was slightly higher under conservation tillage as compared to conventional tillage. Highest seed cotton yield was recorded in

the treatment receiving 100 % RDF followed by 50 % RDF + 50% N (FYM). Significantly higher content of macronutrients *viz.,* N, P, K, S and Mg were recorded in the treatment receiving 100 % RDF followed by 50 % RDF + 50 % N (FYM). It was also noticed that the total uptake of nutrients increased from square initiation to boll development stage as the age of the crop advances towards maturity.

Shariff *et al.* (2017) observed that among the interactions of soil amendments and organic foliar spray, spraying of 3% panchagavya in combination with FYM 1/3 + vermicompost 1/3 + gliricidia green leaf manure 1/3 has recorded significantly higher number of pods/plant, pod length, number of seeds per pod, seed yield per plant and seed yield per hectare over control (RDF + FYM 5 t/ha + water spray). The seed yield of greengram is the product of various yield attributing characters like number of pods, pod length, number of seeds per pod and test weight and these differed significantly due to application of soil amendments, organic foliar spray and their combined application as compared to other treatment combinations and control.

Chandel *et al.* (2017) studied the effect of INM on soil fertility and productivity of cotton + greengram intercropping system in Vertisols and the results after 29th cycle indicated that the application of 50% N through FYM/gliricidia + 50% N through inorganics + 100% P_2O_5 ha^{-1} to cotton + greengram (1:1) intercropping system resulted in sustaining crop productivity and build up fertility status of Vertisols under rainfed condition.

Khambalkar *et al.* (2017) conducted experiment on nutrient dynamics and productivity of cotton in Vertisols under integrated nutrient management and the results revealed that the significantly higher seed cotton yield was recorded with the application of 50% N through gliricidia + 50% N through inorganics + bio-fertilizers+ 100% P + 25 kg K ha^{-1} and it was on par with the application of 100% NP + bio-fertilizers + 25 kg K ha^{-1}.

Pujar and Angadi (2017) studied the effect of INM on yield attributes, yield and production efficiency of cotton and soybean intercropping system. Results revealed that all the yield components like number of bolls per plant, boll weight, seed cotton yield and cotton stalk yield

in cotton and number of pods per plant, seed weight per plant, seed yield in soybean were higher under sole crop, followed by 150% RDF for cotton and soybean intercropping system. However, the land equivalent ratio (LER), area time equivalent ratio (ATER) and cotton equivalent yield (CEY) were higher in 125% RDF for cotton and soybean intercropping system, which was on par with 100% RDF for cotton and soybean + vermicompost 1.25 t ha^{-1}+ gliricidia 2.5 t ha^{-1}. These treatments proved most optimum for better use of growth resources in intercropping system.

Singh (2017) conducted **a** field experiment to study the effect of graded levels of K and S on growth, yield, quality and nutrient uptake of greengram (*Vigna radiata*). The results revealed that growth and yield parameters of greengram increased significantly with increasing levels of K. Increasing sulphur levels showed significant improvement in plant height, pods/plant, grains/pod and test weight over the control. Similarly, application of 40 kg S ha^{-1} resulted in higher grain yield than the yield obtained in the control. Similar increase in straw yield was recorded over control. The uptake of N, P, K and S in greengram crop increased significantly with increasing levels of potassium. The content and yield of protein in greengram grain increased significantly with the addition of K and sulphur.

Chaudhari *et al*. (2018) conducted an experiment to study the effect of graded levels of potassium on growth, yield and quality of blackgram. The results emerged out clearly indicated that various growth parameters like plant height, germination percentage, number of pods, dry matter and seed yield was increased due to application of potassium. It was inferred from the results that application of 25 kg N, 50 kg P_2O_5 and 30 kg K_2O per hectare found superior over only N and P application *i.e.* RDF (25:50:00 N, P_2O_5 and K_2O kg ha^{-1}). The K application showed synergistic effects on other nutrients (N, P, K) uptake. Soil fertility was also found to be improved due to application of potassium to black gram.

Naik *et al.* (2018) studied the influence of potash management through gliricidia green leaf manuring on soil fertility and cotton productivity in Vertisols during *kharif* 2015 at Research field of AICRP for Dryland Agriculture, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra

and reported that conjunctive application of 100 % NP + 10 kg K (inorganic) + 20 kg K ha^{-1} through gliricidia green leaf manuring at 30 DAS resulted in improvement in soil fertility and higher yield of cotton grown in Vertisols under rainfed conditions.

Pujar *et al*. (2018) carried out an experiment to study response of cotton and soybean intercropping system to INM. Results revealed that all the yield components like number of bolls per plant, boll weight, seed cotton yield and cotton stalk yield in cotton and number of pods per plant, seed weight per plant, seed yield were higher under sole crop. Application of 150 and 125% RDF for cotton and soybean intercropping system recorded higher yield and yield components of cotton and soybean. Application of 125% RDF for both crops was found to be agronomically feasible, economically viable, environment friendly and in sustainable approach. In addition to this it provides insurance against inter-climatic changes.

Chandel *et al.* (2018) conducted experiment on long term impact of integrated nutrient management on biological properties of soil and yield sustainability under cotton + greengram (1:1) intercropping system in Vertisols. The results after 30^{th} cycle (2016-17) indicated that long term integrated use of 50% N through FYM/gliricidia + 50% N through fertilizers + 100% P_2O_5 ha^{-1} not only significantly improved biological properties of soil but it was found as the most promising approach from the view point of yield sustainability of cotton + greengram (1:1) intercropping system in Vertisols under rainfed condition.

Satpute *et al.* (2018) conducted an experiment to assess the effect of mineral fertilizer and gliricidia green leaf manuring on yield and nutrient uptake by soybean in Vertisols. The results revealed that the application of 50% N through gliricidia + 50% N through inorganics + bio-fertilizers + 25 kg K ha^{-1} resulted in higher yield and nutrient uptake by soybean. Hence, it is concluded that combined application of gliricidia green manuring along with chemical fertilizers is beneficial for higher nutrient uptake and productivity of soybean in Vertisols under rainfed conditions.

Jadhao *et al.* (2018) worked on the effect of potash application through gliricidia green leaf manuring on yield and nutrient uptake by

soybean. The results indicated that application of 100 % RDF (30:75:30 NPK kg ha^{-1}) resulted in higher nutrient uptake and soybean yield and was found to be on par with application of 75% N + 100% P + 15 kg K (inorganic) + 15 kg K through gliricidia. Hence, it is concluded that conjunctive application of 75% N + 100% P +15 kg K through chemical fertilizers + 15 kg K through gliricidia green leaf manuring at 30 DAS resulted in higher nutrient uptake and yield of soybean grown in Vertisols under rainfed conditions.

Satpute *et al.* (2019) conducted an experiment to assess the impact of potash application through gliricidia green leaf manuring on yield and nutrient uptake by cotton in Vertisols and revealed that the use of gliricidia green leaf manuring in conjunction with chemical fertilizers resulted in higher seed cotton yield and nutrient uptake by cotton. The application of 100% NP + 10 Kg K (inorganic) + 20 kg K through gliricidia was found to be beneficial for higher yield and nutrient uptake by cotton in Vertisols.

2.2. Effect of integrated nutrient management on potassium fractions in soil

Sharma and Verma (2000) conducted an experiment in acid Alfisols of Palampur and they observed that among different K fractions, water soluble-K fraction increased up to 45 per cent by adding lantana (*Lantana camera*) as a source of K over a period of time.

Verma and Sharma (2000) conducted a long term experiment to study the effect of rice straw and FYM application on different K fractions in rice-wheat cropping system. The results indicated that rice straw treatment showed the higher values of available and water soluble K than FYM treated soil, as rice straw contains higher percentage of K than FYM.

Singh *et al.* (2000) examined the impact of integrated use of FYM and fertilizer N in soybean-wheat cropping system on soil K status and found that the continuous application of FYM to soybean @ 4, 8 and 16 t ha^{-1} increased NH_4OAc-K and 0.1M $CaCl_2$-K. Application of FYM increased the NH_4OAc and 0.1M $CaCl_2$ extractable K but the reverse was true with the

application of fertilizer N alone. A declining trend in small quantity was noted in non exchangeable K on application of FYM and nitrogen fertilizer.

Pannu *et al.* (2001) noticed that K content was higher in the surface layer (0-7.5 cm) and decreased with depth up to 30 cm. The treatments receiving wheat straw + GM +rice straw maintained the maximum level of non-exchangeable K followed by FYM plus GM and rice straw. They further reported that non-exchangeable K increased with soil depth and incorporation of rice straw continuously for five years increased all the K fractions compared to its removal.

Majumdar *et al.* (2002) revealed that the water soluble, exchangeable, available and non-exchangeable K increased significantly with increasing dose of K in sweet potato, while lattice and total K remained almost unchanged. Application of FYM significantly increased water soluble, exchangeable, available and non-exchangeable K in soil.

Ved Prakash *et al.* (2002) reported that the available K content in the soil after 27 crop cycles of soybean-wheat, showed differential changes, depending on the yield response to added fertilizers. In surface layer, the available K remained unchanged under 100% NK and 100% N + FYM treatments, whereas significant build up of K was noticed under 100% NPK + FYM. Significant depletion of available K was observed under control, 100% NP and 100% NPK treatments, under 0-15, 15-30 and 30-45 cm depth of soil, respectively. Non exchangeable K content also showed considerable depletion throughout the soil profile under all the treatments.

Surekha *et al.* (2004) noticed that partial K balance was positive with crop residue treatments and negative when straw was removed. Available potassium increased significantly with incorporation of straw or its ash over control. Incorporation of rice straw alone or in combination with green manure increased the available P and K as compared to chemical fertilizers.

Singh *et al*. (2005) conducted the study on leaching of potassium from organic manures and crop residues and inorganic fertilizers

and reported that the maximum water soluble K was increased with the application of FYM, green manure and rice straw.

Kumar *et al.* (2005) analyzed surface soils collected after 28 years of continuous cropping and fertilizer use on an Alfisol in Ranchi, Bihar and observed an increase in the available K, water soluble K, exchangeable K, non-exchangeable and reserve K with increase in level of K application and decrease in treatments where K was not applied over years. Liming had positive influence on exchangeable and reserve K forms in soil. Organic manure application along with balanced use of NPK fertilizers maintained higher amount of K in water soluble, exchangeable and reserve forms in soil compared to that with NPK alone. The value of step K, constant rate K and cumulative K release were higher in soils where K was added alone or along with farmyard manure and lower in soils receiving no K application. Water soluble K, reserve K, step K and cumulative K release were correlated with soil organic carbon content.

Kaur and Benipal (2006) conducted an experiment at Punjab Agriculture University Research farm to study the effect of crop residue and FYM on potassium forms and observed that the rice straw had higher amounts of available and water soluble potassium, whereas FYM had considerable amount of all the forms of potassium. The soils showed increase in available potassium status.

Yaduvanshi and Swarup (2006) studied the effect of NPK fertilizers alone and in combination with green manuring (*Sesbania aculeata*) or farmyard manure (FYM) on potassium (K) balance and release properties in rice-wheat cropping sequence on Aquic Natrustalfs. In all the fertilizer and manure treatments removal of K in the crop exceeded K addition and the total soil K balance was negative. Apparent potassium use efficiency of applied K in the 100% NPK treated plot was lower as compared to 100% NPK + GM and 100% NPK + FYM treated plots. It was observed that in plots receiving fertilizer K, the contribution of non-exchangeable K to plant uptake was lower as compared to without K fertilization (control, 100% N and 100% NP).

Srinivasarao *et al*. (2006) studied the non-exchangeable

potassium release from a Tropoquept as influenced by long term cropping, fertilization and manuring and reported that continuous cropping in an Inceptisol without K and with recommended levels of N and P resulted in considerable decline in native K fertility of the soil.

Bhattacharya *et al.* (2008) studied the effect of 30 years of continuous cropping, fertilization and green manuring on potassium balance and availability in Typic Haplaquepts under rainfed soybean- wheat cropping and reported that in the surface (0-15 cm) layer exchangeable K declined in control, NP and NPK treatment, whereas, a significant accumulation of exchangeable K occurred in the NK and NPK + FYM treated plots.

Sood *et al.* (2008) reported that among the various treatments maximum amount of water soluble K was recorded in 150 per cent NPK treated plots whereas exchangeable K was more in 100 per cent NPK + FYM followed by 150 per cent NPK treated plots. Continuous application of potassium fertilizer with N and P maintained the higher levels of non-exchangeable K. Generally all the fractions decreased with depth.

Brar *et al.* (2008) observed in their investigation on potassium release kinetics of long-term fertilizer experiment that non-exchangeable K release was higher in soils receiving organic manures and chemical fertilizers than the soils not treated with K, the release of non-exchangeable K was faster initially which slowed down afterwards. Potassium release rate coefficients suggested that there was medium rate of release of non-exchangeable K.

Nawlakhe and Mankar (2009) carried out a field experiment under rainfed condition at AICRP for Dryland Agriculture CRS, Dr. PDKV, Akola and reported that addition of pure organic or in combination with inorganic fertilizers increased the available potassium content of soil as compared with exclusive chemical fertilizer treatment and control.

Jatav *et al.* (2010) conducted a field experiment to investigate the role of organic and inorganic sources of phosphorus and potassium on availability of nitrogen and potassium. They reported that total N and available K were higher when 75 per cent phosphorus and potassium was

applied through inorganic fertilizers and 25 per cent from FYM.

Gurumurthy and Prakasha (2011) analyzed different forms of potassium in surface soils under different land use systems in Karnataka and reported that water soluble K ranged from 11.6 to 12.6 mg kg^{-1} soil with an average of 12.1 mg kg^{-1}. The exchangeable K ranged from 126.8 to 140.9 mg kg^{-1} soil with an average of 137.5 mg kg^{-1}. The non-exchangeable K ranged from 220.6 to 232.8 mg kg^{-1} soil with an average of 228.8 mg kg^{-1}. The mineral K ranged from 1.27 to 1.45 % with an average of 1.31 %. The total K ranged from 1.2 to 1.49 % soil with an average of 1.35 % in rice growing soil.

Uddin *et al.* (2012) studied the distribution of forms of potassium in Inceptisol of Badola block in Janjgir district of Chhattisgarh and reported that the water soluble, exchangeable and non-exchangeable K were in the range of 3.9 to 16,44.1 to 153.7 and 177.3 to 456 mg kg^{-1} with mean values of 7.69, 98.56 and 304.71 mg kg^{-1}, respectively.

Sharma *et al*. (2013) while studying a long-term field experiment with rice-wheat cropping observed that the incorporation of lantana (10 to 30 Mg ha^{-1}) over the last 12 years has resulted in a significant build-up of all the K fractions, the maximum being in water-soluble K followed by exchangeable K and least in non-exchangeable K over no lantana incorporation.

Kundu *et al.* (2014) reported that application of potassium increased the different forms of the K in soils, *i.e.* available, water soluble, exchangeable, non-exchangeable, total and lattice forms ranged from 86.9 to 132.4 mg kg^{-1}, 15.4 to 48.2 mg kg^{-1}, 68.9 to 80.9 mg kg^{-1}, 658.9 to 764.5 mg kg^{-1}, 15579.2 to 17250.2 mg kg^{-1} and 14801.3 to 16361.0 mg kg^{-1}, respectively for surface soil and 98.5 to 135.6 mg kg^{-1}, 21.5 to 49.1 mg kg^{-1}, 72.9 to 92.2 mg kg^{-1}, 701.0 to 789.9 mg kg^{-1}, 15753.5 to 17303.2 mg kg^{-1} and 14951.3 to 16378.4 mg kg^{-1}, respectively for sub-surface soil.

Chatterjee *et al.* (2014) conducted an experiment to study the fraction, uptake and fixation of potassium (K) and showed that, available and non-exchangeable potassium was highest in Vertisol and Inceptisol,

respectively.

Singh *et al.* (2014) reported that different forms of K in soil indicated increase in available K with respect to initial level. The change in non-exchangeable K and water soluble K was also noted but was statistically not significant. Apparent K balance study clearly demonstrated negative balance in almost all nutrient management options (control, N, NP, 50% NPK, 100% NPK, 100% NPK+ hand weeding and 150% NPK), except NPK+FYM. However, increase in total K content was found in surface layers in plots that received fertilizer K and FYM compared to fallow plot even after continuous rice-wheat cropping for 40 years at Jabalpur in Vertisols.

Jadhao *et al*. (2015) conducted an experiment to assess the effect of long term manuring and fertilization to wheat on potassium dynamics under rice-wheat cropping sequence in Vertisols at Raipur and reported that application of 100% NPK + FYM @ 5 t ha^{-1} significantly increased the fractions of K *viz*., water soluble K (38.02 mg kg^{-1}), exchangeable K (225 mg kg^{-1}), non-exchangeable K (1238 mg kg^{-1}), lattice K (13673 mg kg^{-1}) and total K (15174 mg kg^{-1}) in 0-15 cm depth.

Kadam *et al*. (2016) observed increase in yield and quality of Bt cotton and the fractions of soil potassium with increasing levels of potassium; also the fractions of potassium in soil decreased at critical growth stages of cotton *viz.*, flowering and boll development due to increasing uptake by cotton. The application of potassium @ 50 kg K_2O ha^{-1} either through MOP or SOP irrespective of sources showed increase in soil potassium fractions and improvement in soil fertility.

Sujatha *et al.* (2017) carried out a field experiment with rice during *kharif* 2015 at Agricultural college farm, Mahanandi to study the influence of different levels of potassium either alone or in combination with green manure on yield and soil K fractions (water soluble, exchangeable, fixed and non-exchangeable forms) at different stages of rice crop and reported that all the forms of K increased with increasing levels of potassium up to 120 kg K_2O ha^{-1} at all the stages of crop growth. The results clearly indicated the increase in fixed K with increasing fertilizer doses from 0 to 120 kg K_2O ha^{-1} at all the stages of crop growth. The highest fixed K and non-

exchangeable K was observed at 120 kg K_2O ha^{-1}. Whereas the highest yield, water soluble and exchangeable form were obtained with the treatment GM+120 kg K_2O ha^{-1} which was on par with GM+80 kg K_2O ha^{-1} and GM+40 kg K_2O ha^{-1}.

Rout *et al.* (2017) evaluated the effect of long-term application of chemical fertilizers and organic manures on soil potassium (K) dynamics, K uptake and yield of hybrid maize under finger millet-hybrid maize cropping sequence. Results showed a significant higher value of available K in soil under 100% NPK + FYM treatment irrespective of critical growth stages of hybrid maize. Among the K fractions, water soluble K was the least in magnitude and lattice K was found to be dominant one. Application of 100% NPK with FYM recorded highest amount of total K as well as all other K fractions emphasizing the importance of organic manure in transformations of different K fractions in soil. Grain and straw yield of hybrid maize were significantly higher under 100% NPK + FYM treatment which was well evidenced by a yield increase of 12.6% over 100% NPK alone. The results on change in soil available K over a period from 1972-2014 under continuous cropping depicts a negative balance of K in soil irrespective of fertilizer treatments imposed, lowest (- 205 kg ha^{-1}) being recorded in 100% NPK + FYM plots.

2.3. Relationship of different potassium fractions with yield of crops

Thippeswamy *et al.* (2000) conducted field experiment at Bangalore and reported that available K was positively and significantly related with 0.1 N HNO_3 extractable K. They further reported that 1 N HNO_3 extractable K was positively and significantly related to K content and grain and straw yield of rice.

Ravankar *et al*. (2001) from a long-term fertilizer experiment at Akola, Maharashtra observed that all the forms of K showed significant correlation with yield of sorghum and wheat crop.

Subehia *et al.* (2003) studied the effect of levels of K and FYM on different forms of K during the different crop growth stages of potato and observed that potassium dynamics equilibrium following K fertilization shifted

towards non exchangeable K with the advancement of crop growth.

Patil *et al.* (2003) conducted a field experiment at Bijapur, Karnataka and reported that K availability in top (0-15 cm) and sub soil (15-30 cm) at harvest was positively and significantly correlated with grain yield of winter sorghum.

Swapana *et al.* (2012) stated that application of 50% NPK through chemical fertilizers + 50% N through organics in *kharif* followed by 100% NPK through chemical fertilizers in *rabi* produced highest (43.37 q ha^{-1}) rice yield. Accordingly, potassium uptake was also higher under this treatment. A significant positive correlation amongst the different forms of potassium in soil suggested the existence of dynamic equilibrium amongst themselves. Grain and straw yield of rice was also positively and significantly correlated with all the fractions of potassium in soil. The degree of correlation in respect of rice yield was highest with exchangeable K (0.535). Uptake of potassium in grain and straw and total K uptake was also positively and significantly correlated with all the fractions of potassium. A highest correlation of total K uptake (0.622) was observed with water soluble K.

Jadhao *et al.* (2016) conducted long term fertilizer experiment at IGKV, Raipur on Vertisol and reported that the application of 100% NPK + FYM @ 5t ha^{-1} significantly increased the fractions of K *viz.*, water soluble K (36.52 mg kg^{-1}), exchangeable K (228 mg kg^{-1}), non-exchangeable K (1214 mg kg^{-1}), lattice K (13852 mg kg^{-1}) in 0-15 cm depth. Among the depth, all the forms of K were significantly higher in surface (0-15 cm) layer as compared to sub-surface (15-30 cm) layer. The contribution of Non-exchangeable K to total uptake was higher with application of NP (3668 kg ha^{-1}) followed by NPK + GM (3046 kg ha^{-1}) and 100% N (2901 kg ha^{-1}). The yield of rice was significantly influenced with the application of 100% NPK + FYM and 150% NPK (64.5 q ha^{-1}). The water soluble K had significant and positive correlations with exchangeable K (r = 0.478) and non-exchangeable K (r = 0.407) indicating dynamic equilibrium among two forms whereas non-exchangeable K was significant with mineral K(r = 0.003) and total K (r = 0.50) indicating difficulty in replenishment of available form of K from mineral K.

Yadav *et al.* (2019) conducted an experiment to assess the effect of potash management through gliricidia green leaf manuring on potassium fractions and the relationship of different potassium fractions with yield of soybean. The results indicated that the significant improvement in potassium fractions was recorded with application of 75% N + 100% P+15 kg K through chemical fertilizers +15 kg K through gliricidia and among the various potassium fractions, the water soluble K was highly correlated with soybean grain yield.

2.4. Correlation studies of potassium fractions

Tiwari and Bansal (1992) found that the exchangeable and water soluble K were interrelated with each other in all the series of northern Madhya Pradesh. While reserve K indicated very high positive relationship with exchangeable K in three series. A significant and positive relationship between total and 1N HNO_3 soluble K was observed in one series, however, in other series it was positive but non significant.

Dhanorkar *et al.* (1994) found from a long-term manurial trial under sorghum-wheat sequence, that available K was significantly correlated with exchangeable, lattice, total and water soluble K. Available K had significant and positive correlation with water soluble, exchangeable and total K and values of coefficient of correlation (r) were 0.71, 0.99, 0.73 and 0.80, respectively.

Chaudhary and Prasad (1997) observed that the water soluble K had significantly positive correlation with exchangeable K (r = 0.776*). Available K was significantly and positively correlated with water soluble K (0.850*) and with exchangeable K (r = 0.977*). Non-exchangeable K was positively and significantly correlated with lattice K (r = 0.747*) and total soil K (r = 0.842*). Lattice K had a positive and significant correlation with total soil K (r = 0.987*).

Yadav *et al.* (1999) observed that the water soluble K was positively and significantly correlated with exchangeable K. Positive and significant relationship between exchangeable, 1N HNO_3 soluble and total K indicates the existence of dynamic equilibrium between these forms of K.

Ahmed and Walia (1999) studied the profile distribution of various forms of potassium in some landforms of Bundelkhand region and reported that available K was positively correlated with non-exchangeable K (r = 0.69) and lattice K (r = 0.53) indicating their contribution towards labile pool of soil K.

Das *et al.* (2000) found that the water soluble K was positively correlated with all the forms of K. Exchangeable K was positively and significantly correlated with available, HNO_3–extractable and non-exchangeable potassium. The non-exchangeable K showed positive and significant correlation with HNO_3-extractable K in all the soils and with total K existence of dynamic equilibrium among the different forms of K.

Subhash Chand and Swami (2000) observed that the exchangeable K was significantly correlated with non-exchangeable K (0.732**), available K (0.744**) and HNO_3 soluble K (0.812**). Non exchangeable K was significantly correlated with available K (0.695**), HNO_3 soluble K (0.828**) and total K (0.455**). These relationships indicate that there existed equilibrium between these forms of K and depletion of one is instantly replenished by one or more of the other forms of K.

Rupa *et al.* (2001) studied the effect of 27 years of continuous cropping, fertilization and manuring on potassium uptake and found that in soils without K fertilization about 100 per cent of total K uptake by the crops was from non-exchangeable reserve as compared to 49.5 and 32.5 per cent when annually 84 kg ha^{-1} K alone and 84 kg ha^{-1} K with 15 t ha^{-1} FYM were applied, respectively. Positive but weak correlation of lattice K was observed with available K however, the non-exchangeable K had significant relationship with available K.

Kaskar *et al.* (2001) reported that water soluble, exchangeable, available, non- exchangeable and lattice K contributed 0.04, 1.39, 1.43, 3.95 and 94.61 per cent towards total soil K in soils. Highly significant positive relationship amongst different fractions of soil K indicated existence of equilibrium between different forms of K in these soils.

Panwar *et al*. (2002) studied the distribution of different forms

of K in twenty surface soil samples in the village Kumawanton-ka-gudan of Udaipur (Rajasthan) and reported that the water soluble K, exchangeable K, HNO_3-K, Morgan K, reserve K and total K of these soils ranged from 4 to 16.8, 30 to 200, 320 to 2080, 19 to 55, 265 to 2020 and 644 to 4166 mg kg^{-1} respectively. The per cent potassium saturation varied from 0.4 to 2.8 with a mean value of 1.1 indicating that most of the soils in this area are poorly saturated with ion. Exchangeable K had high correlation with K saturation per cent, Morgan K and organic carbon whereas water soluble K was found to have negative correlation with organic carbon and pH of soils. HNO_3 extractable K had high correlation with total K and reserve K and also with soil properties like CEC, silt and clay.

Prakash *et al.* (2002) found that non-exchangeable K contributed 96.25 and 49.02 per cent to total potassium removal under NP and NPK treatments, respectively.

Demirtas *et al.* (2003) conducted the study to determine potassium test values for the soils of Agr and Eleskirt plains, which have high agricultural potential under the ecological conditions of Eastern Anatolia, Turkey. Soil samples collected from 30 different locations were evaluated in a greenhouse study. Soils were mostly medium or fine textured. The relationships between soil properties and potassium availability were determined. Result indicated that there were significant relationships between plant potassium levels and available potassium content of soil (r=0.639), exchangeable potassium of soil at the beginning of the study (r=0.604), potassium content of saturation extraction (r=0.558) and extractable potassium in nitric acid (r=0.513).

Rakesh Kumar *et al.* (2004) while studying the suitability of different potassium availability indices for maize in acid soils of Jharkhand, reported that in low land soil, the correlation coefficient (r) values between the indices of K availability and K uptake were found in order: 1 N HNO_3 extractable K > NH_4OAc-K > water soluble K > 0.5 N HCl extractable K > constant rate-K > 0.01 M $CaCl_2$ extractable K.

Gangopadhyay *et al.* (2005) found that the non-exchangeable K showed significant positive correlation with lattice-K (r=0.61**) and total-K

(r=0.67**) while lattice-K showed significant positive correlation with total-K (r=0.99**).

Sharma *et al.* (2006) studied the relationship between potassium (K) fractions with landforms and the association of K fractions with soil properties in a Himalayan catena and observed that All forms of K were positively related to silt and negatively to sand. Exchangeable and total forms of K were positively correlated with clay and CEC. The positive coefficient of correlation amongst the forms of K suggests that K forms are present in dynamic equilibrium.

Singh *et al.* (2006) while studying the forms of potassium in the soils orders Entisols, Inceptisols, Alfisols and Ultisols in the state of Manipur found that all the K fractions showed positive correlation with clay and organic carbon in both thermic and hyperthermic temperature regimes.

Babar *et al*. (2007) studied fourteen profiles from five districts of Central and Eastern Vidarbha region of Maharashtra for the potassium fraction distribution and the interrelationship between forms of potassium. The available, water soluble, exchangeable, non-exchangeable and lattice K contributed 1.97, 0.12, 1.88, 11.25 and 86.76 per cent towards total K. The increase in available K significantly correlated with exchangeable K (r = 0.996**) in Central Vidarbha whereas total and lattice K was highly significant and positively correlated with each other in Central Vidarbha (r = 0.995**) and Eastern Vidarbha (r = 0.995**).

Sharma *et al*. (2009) reported that the water soluble K showed significant and positive correlation with exchangeable K (r = 0.762**) but non significantly correlated with mineral and total K. Non-exchangeable K had highly significant and positive relationship with mineral (r = 0.458**) and total K.

Timtong *et al.* (2010) revealed that there is much closer linear relationship between plant K content and NH_4OAc-K (R^2 = 0.97) with the plant K content being numerically equal to exchangeable K content of the soil (*i.e.* slope of regression line is nearly unity.This relationship indicates that exchangeable K is practically the only form of K available to plants and

that non-exchangeable K is not readily available for plant growth over a period of 180 days.

Sawarkar *et al.* (2013) studied long term fertilizer experiment after thirty six years of soybean–wheat cropping sequence on Typic Haplusterts at Jabalpur and concluded that, K fractions (water soluble- K, exchangeable-K, non-exchangeable-K, lattice-K and total-K) were significantly decreased with increasing soil depth. The contribution of different K fractions at various soil depths studied was in order of lattice-K > non-exchangeable-K > exchangeable-K > water soluble-K. All the K fractions at 0-20 cm soil depth exhibited significant and positive correlation with yield. Minimum depletion of K rate was recorded in 100% NPK+FYM (-2.08 kg ha^{-1} yr^{-1}) to that of other treatments, while control showed maximum K depletion rate (-4.65 kg ha^{-1} yr^{-1}).

Dutta and Zaman (2013) studied the forms of potassium in farmer's fields of shallow tube well command areas of central Brahmaputra valley zone, Assam. They reported that Available K exhibited significant and positive relationship with organic carbon (r = 0.19) and CEC (r = 0.21) and highly significant with clay content (r = 0.32) in these soils.

Sharma (2013) evaluated various land use systems for some important physical and chemical properties and different forms of K. The total K, 1N NH_4OAc-K, water soluble-K, 1N HNO_3-K and 0.01M $CaCl_2$-K ranged between 1641 and 3455, 61.3 and 130.0, 4.8 and 9.5, 865 and 1497 and 16.4 and 36.3 mg kg^1, respectively. Wide variations in K content were observed in four extractants and highest values were recorded in boiling 1N HNO_3 K. The available K, water soluble K, boiling 1N HNO_3-K and 0.01 M $CaCl_2$-K constituted 3.7, 0.3, 45.1 and 1.1% towards total K in these soils. Highly significant and positive relationship amongst different forms of K indicated an existence of dynamic equilibrium among various forms of K. All fractions of K were significantly and positively correlated with SOC.

Jat *et al.* (2014) reported significant increase in grain yield, straw yield, K uptake, and different K fractions in the soil (exchangeable K, water soluble K, Morgan's extractable K, lattice K and total K in the soil) with increase in K levels from 0 to 60 kg K ha^{-1}. Water-soluble K showed

significant and positive correlation with exchangeable K (r = 0.928), Morgan's extractable K (r = 0.983) and lattice K (r= 0.969), indicating rapid equilibrium establishment between these forms. Step wise regression analysis using different pools of K revealed the importance of water soluble K and lattice K influencing crop yield and K uptake by wheat.

Lungmuana *et al.* (2014) studied the distribution and variation of potassium in rice growing soils of red and laterite zone of West Bengal and reported that all the forms of K showed a positive trend of correlation among themselves largely corroborating the well-known concept of existence of a dynamic equilibrium among different forms of K present in soil.

Saini and Grewal (2014) studied distribution of different forms of potassium in soils from different crop rotations (pearlmillet - wheat; cotton-wheat; pearlmillet-mustard; paddy-wheat; sorghum-wheat) on light textured soils and observed that the distribution of the different forms of potassium *i.e.* water soluble, exchangeable, non-exchangeable and total potassium in these soils ranged from 8 to 58 kg ha^{-1}, 127 to 263 kg ha^{-1}, 442 to 828 kg ha^{-1} and 1.18 to 1.92 %, respectively. Correlation study showed that the different forms of potassium were positively and significantly correlated with organic carbon, silt and clay content of the soils. The different forms of potassium were positively and significantly correlated among themselves.

Uzoho and Ekeh (2014) evaluated potassium fractions of different soils and concluded that total, structural or mineral, non-exchangeable or fixed, available, exchangeable and solution K ranged from 11.65-20.35, 11.52-19.65, 0-2.25, 0.07-0.92, 0.05-0.90 and 0.002-0.022 cmol (p+) kg^{-1} respectively, with distributions varying with soil depths for each land use type. Inter-correlationship amongst the K forms was significant ($P \leq 0.05$) between available K and exchangeable K and structural K with total K but non distinct ($P \leq 0.05$) between the other K forms. The regression model showed that non-exchangeable, exchangeable, structural and total K accounted for 39, 51, 96 and 97% of soil available K.

Kalyani *et al.* (2015) conducted a greenhouse experiment on coarse textured soil at Rangareddy (AP) and studied the response of Cauliflower to K application. The amount of K extracted by different

extractants was more in sandy clay loam soil of Mominpet and very low in sandy soils of Emamguda. The NH_4OAC extracted an amount of 54.2 to 242.3 mg kg^{-1} with an average of 130.3 mg kg^{-1} and it showed highly significant correlation with 0.2 m $NaBPh_4$ extractable K (r= 0.926), plant K uptake (r= 0.931) and also with curd yield (r=0.975) of cauliflower.

CHAPTER III

MATERIAL AND METHODS

With a view to study the “Long term effect of integrated nutrient management on soil fertility, potassium fractions and yield of cotton + greengram (1:1) intercropping system in Vertisols” the study was conducted during 2019-20 on a field experiment initiated during 1987-88 at the research field of AICRP for Dryland Agriculture, Dr. PDKV, Akola, Maharashtra. The details of material used and methods adopted during the course of investigation are described below under appropriate heads.

3.1 Material required

- 3.1.1 Climate and weather conditions
- 3.1.2 Soil
- 3.1.3 Experimental details
- 3.1.4 Treatment details
- 3.1.5 Organic materials and fertilizer application

3.2 Methods adopted

- 3.2.1 Collection and processing of soil samples for analysis
- 3.2.2 Soil physical analysis
- 3.2.3 Soil chemical analysis
- 3.2.4 Forms of Potassium

3.3 Cotton + Greengram yield

3.4 Rain water use efficiency

3.5 Statistical analysis

3.6 Location, duration and season of experiment

3.1 Material Required

3.1.1 Climate and weather conditions

Akola is situated in between 22^0 41' N latitude and 77^0 02' E longitudes, at an altitude of 307.4 m above mean sea level and has a subtropical climate. The climate is characterized by three distinct seasons *viz.,* summer becoming hot and dry from March to May. Monsoon characterized as warm rainy from June to October and winter with dry mild cold from November to February. Most of the rainfall is received from south west monsoon.

Monthly weather data recorded at Agro-meteorology Observatory, Dr. PDKV, Akola during 2019-20 along with corresponding normal are presented in Table 1. Weather situation during 2019-20 and the crop season have been described briefly in following sections.

Rainfall

Month wise rainfall distribution at Akola during June 2019 to March 2020 is presented in Table 1 and depicted in Fig 1. The month wise data along with normal on various other weather parameters recorded at Agro-meteorology Observatory, Dr. PDKV, Akola during 2019-20 is also presented in Table 1. Rainfall during *kharif* 2019 (June- September) amounted 817.9 mm which was + 18.6% of the corresponding normal rainfall (689.5 mm). Monthly rainfall during June, July, August and September amounted to 89.6, 258.7, 179.5 and 263.1 mm which was -40.5, +34.6, -16.7 and +136.8 per cent of the monthly normal (1981-2010), respectively. During post monsoon period (October- December) rainy day events recorded were 10 days, amounting to 111.1 mm rainfall. Remaining post monsoon months (November to December) and winter months (January and February) did not receive any rain day event. Further rainless weather continued across March month also. Total rainy days during June to September were 47 as against the normal of 37 days.

Air Temperature

The average maximum high temperature of 43.1^{0}C was recorded in May 2019 while, average minimum low temperature of 10.5^{0}C was recorded in January 2020.

By and large, the temperature deviation showed mostly below normal trend with very few occasions above normal deviation across the season.

Relative Humidity

The higher relative humidity of 92% was observed in September 2019 and the lower relative humidity of 39% was observed in May 2019. Higher humidity range across most part of the monsoon season was due to rainy/cloudy monsoon atmosphere. Overall actual evening relative humidity more or less followed the trend of morning relative humidity.

Pan Evaporation

The higher pan evaporation of 15.2 mm was recorded in May 2019 while, the lower pan evaporation of 2.8 mm was recorded in September 2019.

Bright sunshine hours

The higher bright sunshine of 9.4 hrs was recorded in May 2019 while, lower bright sunshine of 2.8 hrs was recorded in August and September 2019.

During the major part of post-monsoon and winter months BSH values were below normal (-0.1 to -7.5 hrs). By and large, lower than normal bright sunshine hours might have interfered with the potential photosynthetic activity of crops. Also it might have facilitated availability of soil moisture for comparatively longer period of time.

Wind speed

Wind speed was lower than normal throughout the *kharif* as well as *rabi* growing season. Except during 38 MW (+0.7 km/hr) of monsoon phase, it remained markedly lower than normal across the *kharif* as well as *rabi* growing season. Lower wind speed keeps the rate of evaporation lower

benefiting *kharif and rabi* crops.

Table 1. Monthly weather data for the year 2019-2020 recorded at Agro-meteorological observatory, Dr PDKV, Akola

																		Actual 2019-20 Normal 1981-2010	
Month	**T MAX (ºC)**		**T MIN (ºC)**		**BSH (hrs)**		**Ws (km/hr)**		**RHI (%)**		**RHII (%)**		**Evap (mm)**		**RF (mm)**		**CRF (mm)**	**Rainy Days**	
2019	**N**	**A**	**N**	**A**	**N**	**A**	**N**	**A**	**N**	**A**	**N**	**A**	**N**	**A**	**N**	**A**		**N**	**A**
JANUARY	29.8	**28.5**	11.4	**10.5**	8.8	**7.6**	5.3	**1.3**	68	**69**	29	**27**	4.8	**4.9**	9.0	**0.0**	**0.0**	0.9	**0**
FEBRUARY	32.5	**32.2**	13.3	**15.6**	9.4	**8.2**	6.2	**3.0**	57	**53**	22	**22**	6.6	**6.4**	10.2	**1.9**	**1.9**	0.8	**0**
MARCH	37.3	**36.7**	17.8	**17.0**	9.6	**8.9**	7.2	**2.7**	41	**44**	19	**20**	6.0	**7.9**	9.5	**0.0**	**1.9**	0.7	**0**
APRIL	41.2	**42.1**	23.2	**22.2**	10.0	**8.6**	9.0	**4.0**	35	**41**	14	**22**	13.7	**10.5**	3.1	**13.5**	**15.4**	0.4	**1**
MAY	42.5	**43.1**	27.0	**26.4**	9.9	**9.4**	14.2	**8.4**	46	**39**	18	**19**	16.8	**15.2**	16.6	**0.0**	**15.4**	1.1	**0**
JUNE	37.2	**40.1**	25.6	**24.7**	7.2	**7.6**	14.9	**9.4**	71	**60**	41	**33**	10.9	**13.1**	150.5	**89.6**	**105.0**	7.9	**6**
JULY	32.5	**32.1**	23.7	**20.9**	4.5	**3.8**	11.9	**8.1**	84	**84**	61	**61**	5.5	**5.6**	212.2	**285.7**	**390.7**	12.6	**16**
AUGUST	30.4	**29.2**	23.0	**20.0**	4.1	**2.8**	11.4	**7.0**	87	**90**	68	**73**	4.4	**4.2**	215.7	**179.5**	**570.2**	9.3	**12**
SEPTEMBER	32.5	**29.9**	22.2	**19.9**	6.6	**2.8**	7.9	**3.8**	84	**92**	57	**72**	5.0	**2.8**	111.1	**263.1**	**833.3**	7.5	**13**
OCTOBER	33.7	**30.5**	18.6	**17.9**	8.4	**5.5**	4.8	**0.8**	76	**91**	39	**60**	5.5	**3.7**	52.3	**85.1**	**918.4**	2.3	**7**
NOVEMBER	31.6	**30.5**	14.1	**14.7**	8.7	**7.3**	4.7	**0.6**	70	**90**	31	**46**	4.8	**3.5**	20.2	**11.8**	**930.2**	1.2	**1**
DECEMBER	28.3	**27.9**	10.6	**15.2**	8.8	**5.2**	4.6	**0.8**	70	**86**	30	**45**	4.3	**3.4**	8.4	**14.2**	**944.4**	0.9	**2**
2020																			
JANUARY	29.8	**27.1**	11.4	**14.3**	8.8	**6.1**	5.3	**1.3**	68	**82**	29	**46**	4.8	**3.8**	9.0	**0.0**	**0.0**	0.9	**0**
FEBRUARY	32.5	**30.8**	13.3	**15.0**	9.4	**7.8**	6.2	**2.0**	57	**68**	22	**30**	6.6	**5.2**	10.2	**0.0**	**0.0**	0.8	**0**
MARCH	37.3	**33.1**	17.8	**19.3**	9.6	**8.4**	7.2	**3.5**	41	**56**	19	**28**	6.0	**8.2**	9.5	**2.5**	**2.5**	0.7	**0**

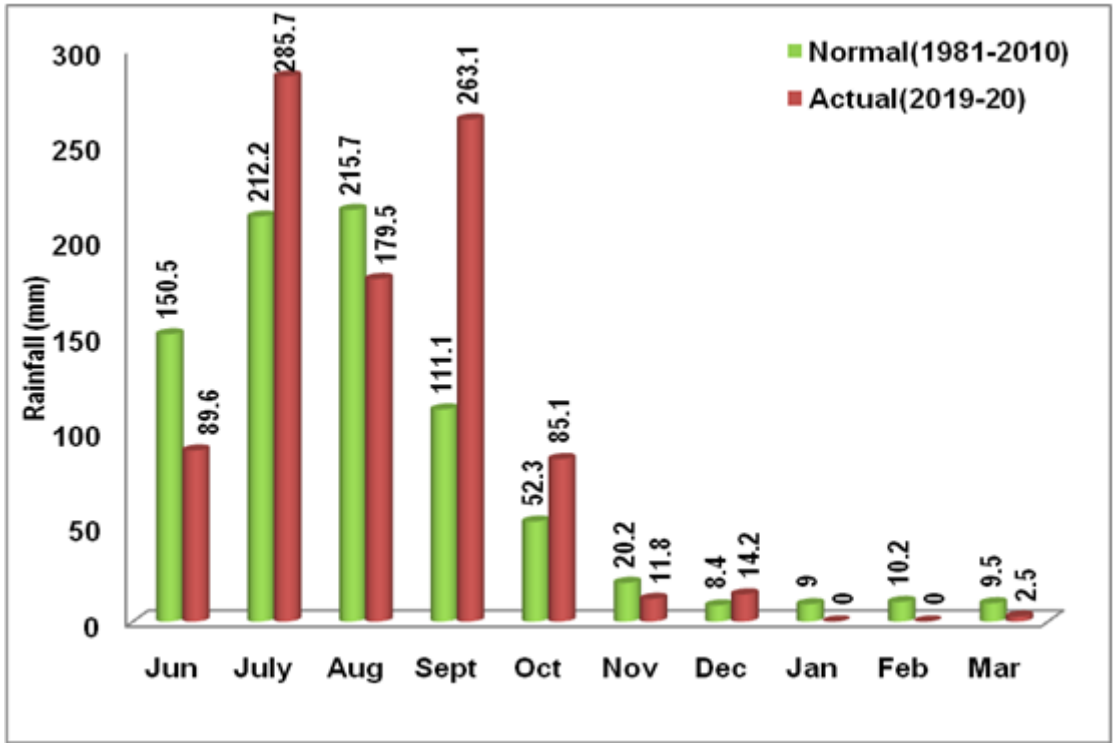


Fig 1. Monthwise rainfall distribution at Akola(2019-20)

3.1.2 Soil

The soil of experimental site was Vertisols which belongs to fine, smectitic, hyperthermic family of Typic Haplusterts.

3.1.3 Experimental details

This experiment was conducted with eight treatments and three replications laid out in a randomized block design (Fig 2) at the Research field of AICRP for Dryland Agriculture, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra.

Details of each treatment and information pertaining to experimental site are given below.

Details of experiment

1. Location : Research field of AICRP for Dryland Agriculture, Dr. PDKV, Akola.
2. Year of start : 1987- 88
3. Year of the study : 2019-20 (33rd cycle)
4. Soil type : Vertisols
5. Crop and variety : Cotton + Greengram(1:1)
   Cotton:AKH 9916,Greengram:Utkarsha
6. Season : *kharif* season (2019-20)
7. Design of experiment : RBD (Fixed site)
8. Treatments : 08 (Eight)
9. Replications : 03 (Three)
10. Spacing : Cotton- 60 X30cm
    Greengram- 60 X10cm
11. Plot size : Gross = 9.0 x 9.9 m^2, Net = 8.4 x 9 m^2
12. Seed rate : Cotton - 10 kg ha^{-1}, Greengram- 9 kg ha^{-1}
13. Method of sowing : Drilling
14. RDF (cotton) : 60:30:30 NPK kg ha^{-1}

Plate 1. Application gliricidia green leaf manure at 30 DAS and overview of experimental field

3.1.4 Treatment details

T_1 Control

T_2 100% RDF

T_3 50% RDF

T_4 50% N ha^{-1} gliricidia

T_5 50% N ha^{-1} FYM

T_6 50% N fertilizers + 50% N gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers

T_7 50% N fertilizers + 50% N ha^{-1} FYM + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers

T_8 100% N ha^{-1} gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers

3.1.5 Organic materials and fertilizer application

3.1.5.1 Application of organic manures

Basal application of FYM and Gliricidia as green leaf manuring was applied per plot at 30 DAS as mentioned in treatment details.

Organic materials *viz*., Gliricidia and Farm yard manure (FYM) were analyzed for their N, P and K content before their incorporation.

Major nutrient content in manure and fertilizer added

Source	**N (%)**	**P (%)**	**K (%)**
Gliricidia(green basis)	0.70	0.08	0.49
FYM	0.51	0.22	0.48
Urea	46	-	-
Single super phosphate	-	16	-
Muriate of potash	-	-	60

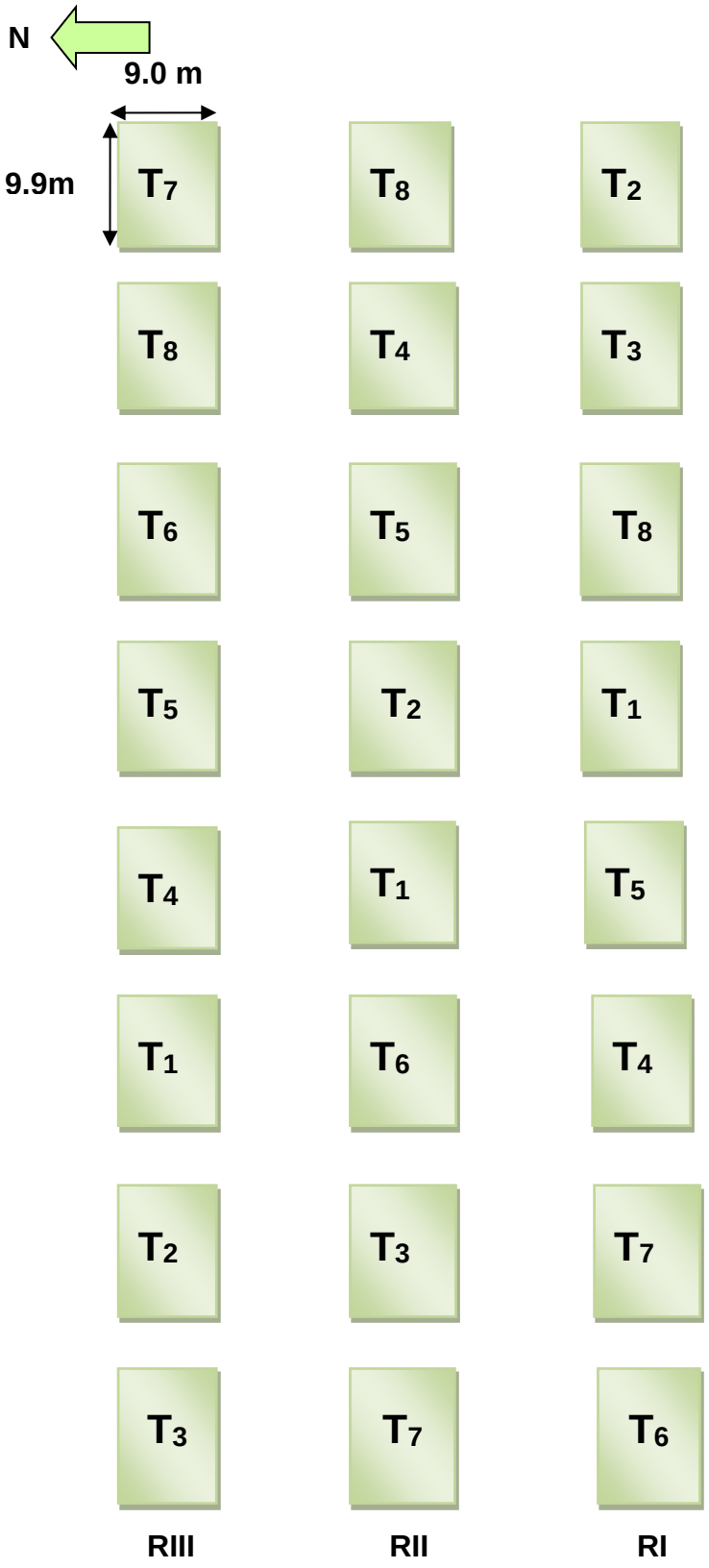


Fig. 2. Plan of layout of experimental field

FYM and Gliricidia application

Treatments		FYM (tonnes/ha)	FYM (kg/plot)	Gliricidia (tonnes/ha)	Gliricidia (kg/plot)
T_1	Control	0	0	0	0
T_2	100 % RDF	0	0	0	0
T_3	50% RDF	0	0	0	0
T_4	50% N ha^{-1} gliricidia	0	0	4	38
T_5	50% N ha^{-1} FYM	6	53	0	0
T_6	50% N fertilizers + 50% N gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	0	0	4	38
T_7	50% N fertilizers + 50% N ha^{-1} FYM + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	6	53	0	0
T_8	100% N ha^{-1} gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	0	0	8	76

3.1.5.2 Application of chemical fertilizers

The recommended dose (60kg N, 30kg P_2O_5 and 30 kg K_2O ha^{-1}) was applied to cotton. Full quantity of the recommended dose of phosphorus and potassium was applied as a basal dose through single super phosphate and muriate of potash respectively. Nitrogen was applied through urea in two-spilt applications, half at the sowing and half at 30 DAS to cotton. As per the treatments gliricidia green leaf manure was applied at 30 DAS.

3.2 Methods Adopted

3.2.1 Collection and processing of soil samples for analysis

The representative soil samples (0-20 cm) were collected from all the plots at harvest of cotton crop. These soil samples were air dried in shade and stored in polythene bags for further analysis. The air-dried samples were carefully and gently ground with the wooden pestle to break the soil lumps

(clods) and were passed through a 2 mm diameter sieve. The sieved samples were mixed thoroughly and stored in polythene bags and properly labelled and preserved for subsequent analysis.

3.2.2 Soil physical analysis

3.2.2.1 Bulk density

Bulk density was determined by clod coating method (Blake and Hartze, 1986).

3.2.2.2 Hydraulic conductivity

Hydraulic conductivity was determined by constant head method as described by Klute and Dirksen, 1986.

3.2.2.3 Mean weight diameter

Mean weight diameter was determined by wet sieving using Yoder's apparatus (Kemper and Rosenau, 1986).

3.2.3 Soil chemical analysis

3.2.3.1 Soil reaction (pH)

Hydrogen ion activity expressed as pH was measured with pH meter using 1:2.5 soil-water suspension (Jackson, 1973).

3.2.3.2 Electrical conductivity (EC)

The clear supernatant extract obtained from soil-water suspension used for pH was utilized for the EC measurement using a conductivity bridge (Jackson, 1973).

3.2.3.3 Organic carbon

Walkley and Black method as described by Jackson (1973) was used to determine organic carbon content of soil.

3.2.3.4 Available nitrogen

Alkaline potassium permanganate method as described by Subbiah and Asija, (1956) was used to determine available nitrogen content of soil.

3.2.3.5 Available phosphorus

It was determined by Olsen's method using 0.5 M sodium bicarbonate (pH- 8.5) as extractant. Darco-G-60 soluble charcoal was used to absorb the dispersed organic matter and make the filtrate colourless for using UV based double beam spectrophotometer (Watanabe and Olsen, 1965).

3.2.3.6 Available potassium

Available potassium was determined by neutral normal ammonium acetate method using Flame photometer (Jackson,1973).

3.2.4 Forms of Potassium

3.2.4.1 Total K

Extracted by HF digestion method and K determined on Flame Photometer (Pratt, 1965).

3.2.4.2 Water soluble K

Extracted by shaking soil and water suspension (1: 5) for 1hour and K determined on Flame Photometer as described by Pratt ,1965.

3.2.4.3 Exchangeable K

Extracted by using 1N neutral ammonium acetate, K on exchangeable complex determined with Flame Photometer (Pratt, 1965).

3.2.4.4 Non exchangeable K

Determined by treating with hot 1 N HNO_3 in 1:10 ratio and boiling for 10 minutes and K estimated with the help of Flame Photometer as described by Pratt, 1965.

3.2.4.5 Lattice K

Calculated by subtracting the sum of above fractions from the total potassium content (Ranganathan and Satyanarayana,1980).

3.3 Cotton + greengram yield

Yield of cotton and greengram was picked from net plots in all the replications and yield per plot and yield per hectare was calculated.

3.4 Rain water use efficiency (RWUE)

It was calculated using yield of crop and total seasonal rainfall as under.

$$\text{RWUE (kg ha}^{-1}\text{mm}^{-1}\text{)} = \frac{\text{Yield (kg ha}^{-1}\text{)}}{\text{Rainfall (mm)}}$$

3.5 Statistical analysis

The level of statistical significance to the experimental data was carried out as per procedure described by Gomez and Gomez (1984).

3.6 Location, duration and season of experiment

The experiment on “Long term effect of integrated nutrient management on soil fertility, potassium fractions and yield of cotton + greengram (1:1) intercropping system in Vertisols” was conducted at research field of AICRP for Dryland Agriculture, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra during *kharif* season 2019-2020.

CHAPTER IV

RESULTS AND DISCUSSION

Results pertaining to study entitled “Long term effect of integrated nutrient management on soil fertility, potassium fractions and yield of cotton + greengram (1:1) intercropping system in Vertisols”, conducted during 2019-20 on a field experiment initiated during 1987-88 at the research field of AICRP for Dryland Agriculture, Dr. PDKV, Akola are tabulated, interpreted and discussed in this chapter under the following heads.

Long term effect integrated nutrient management on:

4.1 Yield of cotton + greengram (1:1) intercropping system

4.2 Physical properties of soil

4.3 Chemical properties of soil

4.4 Soil fertility

4.5 Potassium fractions in soil

4.6 Contribution of different potassium fractions to total K

4.7 Correlation among yield and various potassium fractions

4.1 Yield of cotton + greengram (1:1) intercropping system

4.1.1 Yield of cotton in cotton + greengram (1:1) intercropping system

The yield of cotton in cotton + greengram intercropping system is presented in Table 2 and depicted in Fig 3. The mean seed cotton yield ranged between 424.6 to 776.3 kg ha^{-1}. Long term application of 50% RDN through organic source *i.e.* FYM in combination with 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through inorganics (T_7) recorded higher seed cotton yield (776.3 kg ha^{-1}) and was on par with the application of 50% N through gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through fertilizers (T_6), application of 100% RDF (T_2) and application of 100% N through gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} through fertilizers (T_8).The increase in seed cotton yield with long term application of 50% RDN through organic source *i.e.* FYM in combination with 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through inorganics (T_7) was 82.8 % and 11.8 % higher as compared to control (T_1) and 100 % RDF (T_2) treatments,

respectively. The lowest seed cotton yield (424.6kg ha^{-1}) was recorded in treatment T_1 *i.e.* control.

Table 2. Effect of long term INM treatments on cotton yield

Treatments		Cotton yield (kg ha^{-1})	
		Seed cotton	**Stalk**
T_1	Control	424.6	828.1
T_2	100% RDF	694.0	1388.3
T_3	50% RDF	626.6	1220.7
T_4	50% N ha^{-1}gliricidia	546.2	1037.9
T_5	50% N ha^{-1} FYM	598.6	1158.0
T_6	50% N fertilizers + 50% N ha^{-1}gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	774.4	1522.7
T_7	50% N fertilizers + 50% N ha^{-1} FYM + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	776.3	1527.7
T_8	100% N ha^{-1}gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	684.6	1314.4
SE (m) ±		38.1	70.7
CD at 5%		113.3	210.1
CV (%)		10.31	9.80

The mean cotton stalk yield ranged from 828.1 to 1527.7 kg ha^{-1} and significantly higher cotton stalk yield (1527.7 kg ha^{-1}) was recorded with long term application of 50% RDN through organic source *i.e.* FYM in combination with 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through inorganics (T_7) and was on par with the application of 50% N through gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through fertilizers (T_6) and application of 100% RDF (T_2). The increase in cotton stalk yield with long term application of 50% RDN through organic source *i.e.* FYM in combination with 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through inorganics (T_7) was 84.5% and 10% higher as compared to control (T_1) and 100 % RDF (T_2) treatments, respectively. The lowest cotton stalk yield (828.1 kg ha^{-1}) was recorded in treatment T_1 *i.e.* control.

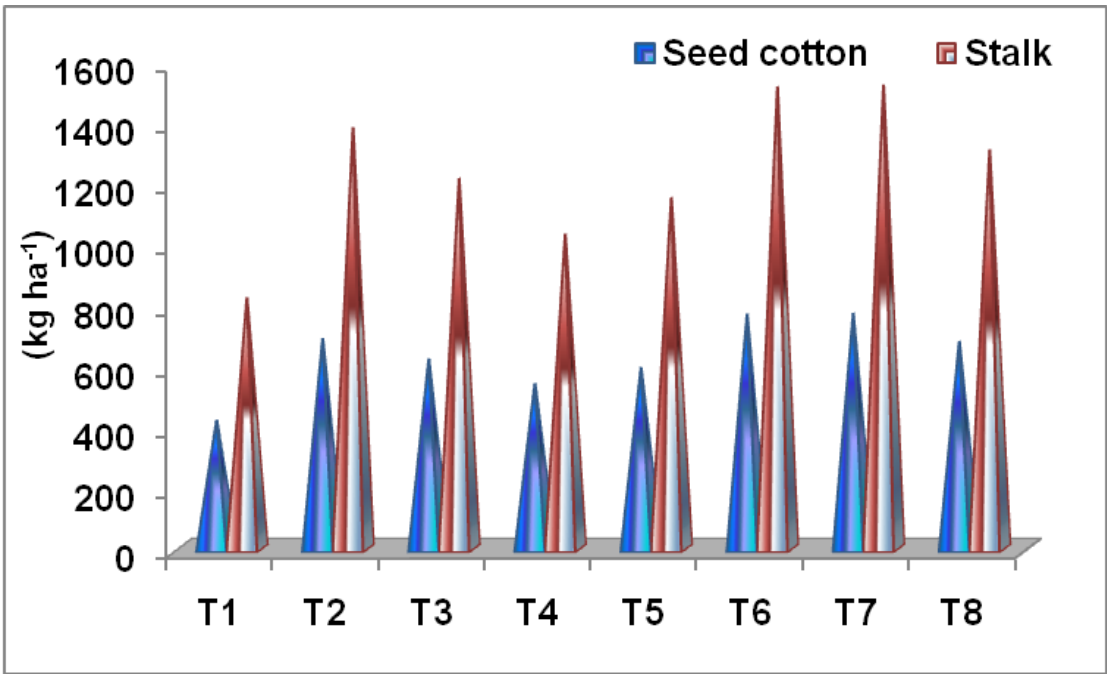


Fig 3. Effect of long term INM treatments on cotton yield

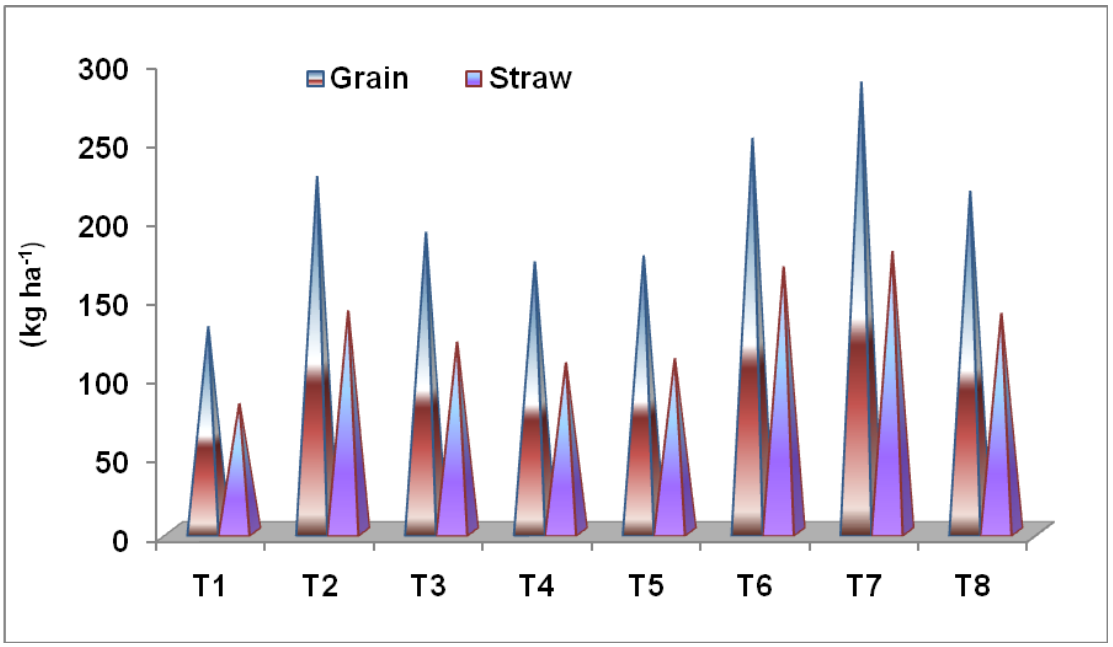


Fig 4. Effect of long term INM treatments on greengram yield

Higher cotton yield with conjunctive application of FYM and gliricidia green leaf manure along with chemical fertilizers may be due to balanced supply of nutrients to the crop throughout the crop growth period. Green leaf manure undergo decomposition during which series of nutrient transformation takes place which helps in their higher availability to the crops and higher uptake of nutrients by the crops will result in higher yield.

4.1.2 Yield of greengram in cotton + greengram (1:1) intercropping system

The yield of greengram in cotton + greengram intercropping system is presented in Table 3 and depicted in Fig 4. The greengram grain yield ranged between 130.9 to 286.2 kg ha^{-1}. Long term application of 50% RDN through organic source *i.e.* FYM in combination with 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through inorganics (T_7) recorded higher greengram grain yield (286.2 kg ha^{-1}) and was on par with the application of 50% N through gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through fertilizers (T_6). The increase in greengram grain yield with long term application of 50% RDN through organic source *i.e.* FYM in combination with 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through inorganics (T_7) was 118.6 % and 26.5 % higher as compared to control (T_1) and 100 % RDF (T_2) treatments, respectively. The lowest greengram grain yield (130.9 kg ha^{-1}) was recorded in treatment T_1 *i.e.* control.

The greengram straw yield ranged between 82.0 to 178.6 kg ha^{-1}. Long term application of 50% RDN through organic source *i.e.* FYM in combination with 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through inorganics (T_7) recorded higher greengram straw yield (178.6 kg ha^{-1}) and was on par with the application of 50% N through gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through fertilizers (T_6). The increase in greengram straw yield with long term application of 50% RDN through organic source *i.e.* FYM in combination with 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through inorganics (T_7) was 117.8% and 26.7% higher as compared to control (T_1) and 100 % RDF (T_2) treatments, respectively. The lowest greengram straw yield (82.0 kg ha^{-1}) was recorded in treatment T_1 *i.e.* control.

Table 3. Effect of long term INM treatments on greengram yield

Treatments		Greengram yield (kg ha^{-1})	
		Grain	Straw
T_1	Control	130.9	82.0
T_2	100% RDF	226.3	140.9
T_3	50% RDF	190.8	121.1
T_4	50% N ha^{-1}gliricidia	172.1	107.9
T_5	50% N ha^{-1} FYM	175.8	110.6
T_6	50% N fertilizers + 50% N ha^{-1}gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	250.6	169.0
T_7	50% N fertilizers + 50% N ha^{-1} FYM + 100%P_2O_5 + 100% K_2O ha^{-1} fertilizers	286.2	178.6
T_8	100% N ha^{-1}gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	217.0	139.4
SE (m) ±		16.0	9.1
CD at 5%		47.5	27.0
CV (%)		13.41	12.00

Higher greengram yield with conjunctive application of FYM and gliricidia green leaf manure along with chemical fertilizers may be due to balanced supply of nutrients to the crop throughout the crop growth period. Green leaf manure undergo decomposition during which series of nutrient transformation takes place which helps in their higher availability to the crops and higher uptake of nutrients by the crops will result in higher yield.

4.1.3 Seed cotton equivalent yield in cotton + greengram (1:1) intercropping system

The data on seed cotton equivalent yield in cotton + greengram intercropping system is presented in Table 4. The seed cotton equivalent yield (SCEY) ranged between 574.94 to 1104.84 kg ha^{-1}. Long term application of 50% RDN through organic source *i.e.* FYM in combination with 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through inorganics (T_7) recorded higher seed cotton equivalent yield (1104.84 kg ha^{-1}) and was on par with the application of 50%

N through gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through fertilizers (T_6). The increase in seed cotton equivalent yield with long term application of 50% RDN through organic source *i.e.* FYM in combination with 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through inorganics (T_7) was 92.2% and 15.8% higher as compared to control (T_1) and 100 % RDF (T_2) treatments, respectively. The lowest seed cotton equivalent yield (574.94 kg ha^{-1}) was recorded in treatment T_1 *i.e.* control.

Table 4. Effect of long term INM treatments on seed cotton equivalent yield

Treatments		SCEY (kg ha^{-1})
T_1	Control	574.94
T_2	100% RDF	953.82
T_3	50% RDF	845.67
T_4	50% N ha^{-1}gliricidia	743.77
T_5	50% N ha^{-1} FYM	800.44
T_6	50% N fertilizers + 50% N ha^{-1}gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	1062.17
T_7	50% N fertilizers + 50% N ha^{-1} FYM + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	1104.84
T_8	100% N ha^{-1}gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	933.73
SE (m) ±		37.25
CD at 5%		110.68
CV (%)		7.35

Higher seed cotton equivalent yield with conjunctive application of FYM and gliricidia green leaf manure along with chemical fertilizers may be due to balanced supply of nutrients to the crop throughout the crop growth period. Green leaf manure undergo decomposition during which series of nutrient transformation takes place which helps in their higher availability to the crops and higher uptake of nutrients by the crops will result in higher yield.

In general, the increase in yield of cotton and greengram was recorded with conjunctive application of FYM and gliricidia green leaf manure

along with chemical fertilizers. Similar observations were recorded by, Solunke *et al.* (2011), Sonune *et al.* (2012), Simon *et al.* (2016), Chandel *et al.* (2017) and Pujar *et al.* (2018).

4.1.4 Rainwater use efficiency (RWUE)

The data on Rainwater use efficiency (RWUE) as influenced by various treatments is presented in Table 5. The Rainwater use efficiency (RWUE) for cotton (0.85 kg $ha^{-1}mm^{-1}$), greengram (0.35 kg $ha^{-1}mm^{-1}$) and seed cotton equivalent yield (1.21 kg $ha^{-1}mm^{-1}$) were higher under integrated nutrient management involving use of chemical fertilizers with FYM (T_7) which was followed by 50% N fertilizers + 50% N gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6).

Table 5. Effect of long term INM treatments on Rainwater use efficiency (RWUE)

Treatments		RWUE (kg $ha^{-1}mm^{-1}$)		
		Cotton	**Greengram**	**SCEY**
T_1	Control	0.46	0.16	0.63
T_2	100% RDF	0.76	0.28	1.04
T_3	50% RDF	0.68	0.23	0.92
T_4	50% N ha^{-1}gliricidia	0.60	0.21	0.81
T_5	50% N ha^{-1} FYM	0.65	0.21	0.87
T_6	50% N fertilizers + 50% N ha^{-1}gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	0.85	0.31	1.16
T_7	50% N fertilizers + 50% N ha^{-1} FYM + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	0.85	0.35	1.21
T_8	100% N ha^{-1}gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	0.75	0.27	1.02

The lowest RWUE was noticed in no manure, no fertilizer plot (T_1) than all the other treatments. The data indicated that integrated application of FYM/gliricidia along with chemical fertilizers resulted in increase in RWUE.

4.2 Physical properties of soil

4.2.1 Bulk density

The data pertaining to bulk density under different treatments are presented in Table 6. It is the ratio of mass of oven dry soil solid particles to the total volume of the soil indicating the air water relationship for the crops. The bulk density of soil before initiation of the experiment was 1.48 Mg m^{-3}. The data pertaining to the bulk density of soil as influenced by various treatments was statistically significant and it ranged from 1.40 to 1.46 Mg m^{-3}, indicating that the lowest (1.40 Mg m^{-3}) bulk density was recorded with the application of 50% N fertilizers + 50% N ha^{-1} gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6) and 50% N fertilizers + 50% N ha^{-1} FYM + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_7). The higher value of bulk density (1.46 Mg m^{-3}) was found in treatment T_1 *i.e.* control.

Table 6. Effect of long term INM treatments on physical properties of soil

	Treatments	BD (Mg m^{-3})	HC (cm hr^{-1})	MWD (mm)
T_1	Control	1.46	0.81	0.58
T_2	100% RDF	1.45	0.93	0.67
T_3	50% RDF	1.44	0.90	0.64
T_4	50% N ha^{-1}gliricidia	1.43	0.96	0.70
T_5	50% N ha^{-1} FYM	1.42	0.97	0.68
T_6	50% N fertilizers + 50% N ha^{-1}gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	1.40	1.11	0.75
T_7	50% N fertilizers + 50% N ha^{-1} FYM + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	1.40	1.12	0.76
T_8	100% N ha^{-1}gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	1.41	1.09	0.73
	SE (m)±	0.01	0.01	0.01
	CD at 5%	0.03	0.04	0.04

The lower values of bulk density in gliricidia and FYM treated plots may be due to aggregation of soil particle due to increasing organic matter as well as stability of aggregates which leads to increase the total pore space in

soil. Similar results were also reported by Kide *et al.* (2008), Rao and

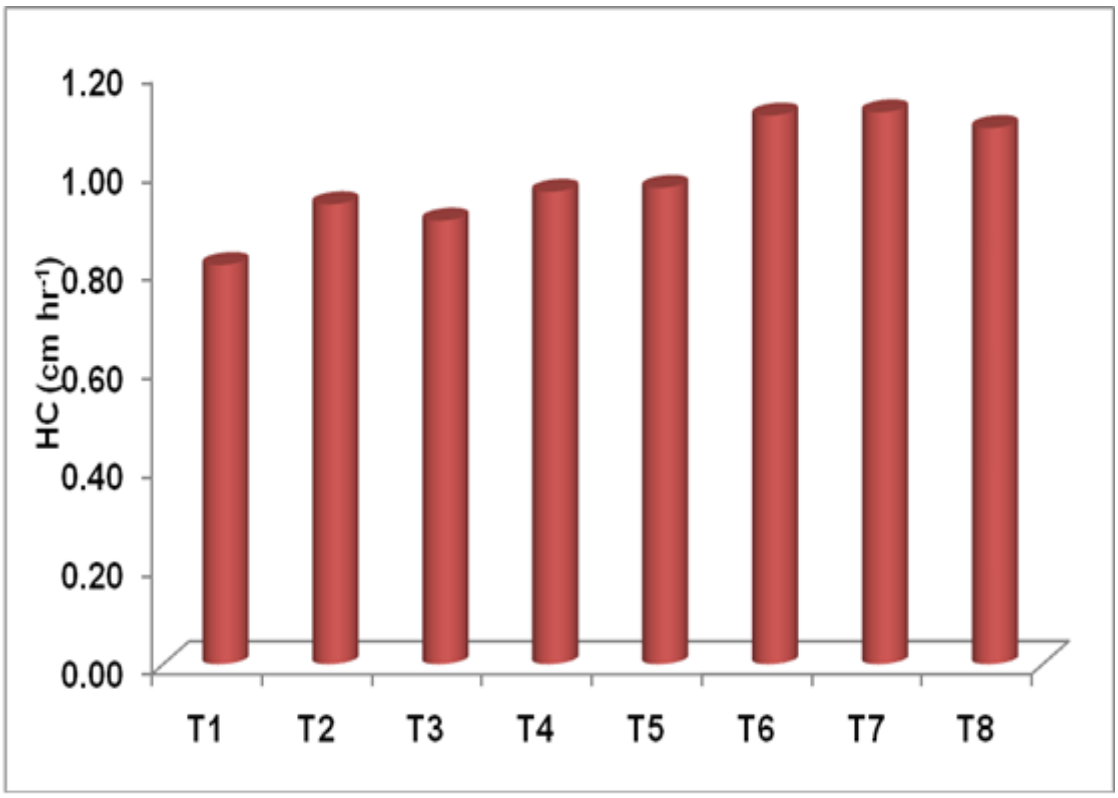


Fig 5. Effect of long term INM treatments on hydraulic conductivity of soil

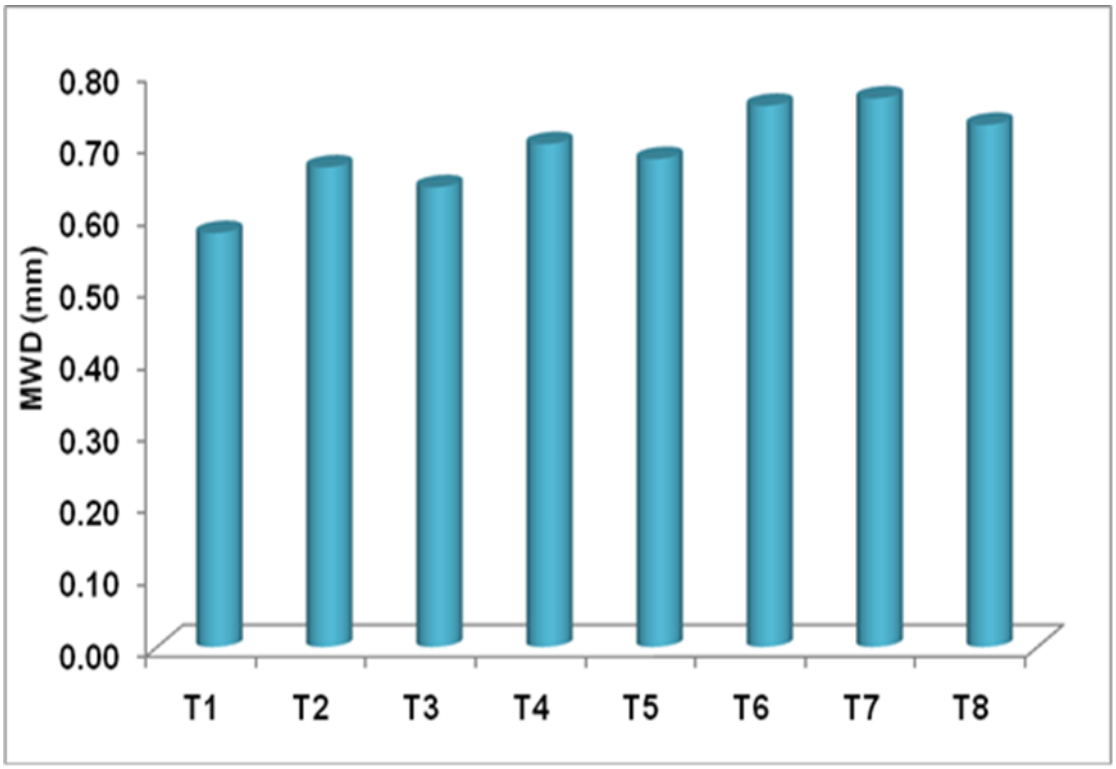


Fig 6. Effect of long term INM treatments on mean weight diameter of soil

Janawade (2009), Bandyopadhyay *et al.* (2010) and Nandapure *et al.* (2011).

4.2.2 Hydraulic conductivity

Data pertaining to hydraulic conductivity under different treatments are presented in Table 6 and depicted in Fig 5. The hydraulic conductivity of soil ranged from 0.81 to 1.12 cm hr^{-1} and the higher (1.12 cm hr^{-1}) hydraulic conductivity was recorded with the application 50% N fertilizers + 50% N ha^{-1} FYM + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_7) and it was found to be on par with application of 50% N fertilizers + 50% N ha^{-1} gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6) and 100% N ha^{-1} gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_8) . The lower value of hydraulic conductivity (0.81 cm hr^{-1}) was found in treatment T_1 *i.e.* control.

Application of FYM and inorganic fertilizer applied in combination recorded higher hydraulic conductivity which might be due to the better soil particle aggregation, microbial respiration, increased pore space and decreased soil bulk density. Similar results were also reported by Bandyopadhyay *et al.* (2010), Gayatri *et al.* (2010) and Nandapure *et al.* (2011).

4.2.3 Mean weight diameter

The data pertaining to the mean weight diameter (Table 6 and Fig 6) of soil aggregate as influenced by different treatments was statistically significant and it ranged from 0.58 mm to 0.76 mm. The highest mean weight diameter (0.76 mm) was observed in the treatment with application of 50% N fertilizers + 50% N ha^{-1} FYM + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_7) and it was found to be on par with the application of 50% N fertilizers + 50% N ha^{-1} gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6) and 100% N ha^{-1}gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_8). The lower value of mean weight diameter (0.58 mm) was found in treatment T_1 *i.e.* control.

The increase in mean weight diameter through the application of FYM and gliricidia in various treatments may be due to the improved soil aggregation by addition of organic matter in the soil. The added organics could supply additional fresh organic residues (water soluble and hydrolysable substrates) and carbon to the soil resulting in the production of microbial polysaccharides that increase aggregate cohesion, which could explain the

progressive increase in aggregate stability to mechanical breakdown indicating an immense need of organics to improve soil physical properties which is reflected in the treatments of INM. Similar results were recorded by Bandyopadhyay *et al.* (2010).

4.3 Chemical properties of soil

Importance of chemical properties of soil in relation to plant growth is widely recognized. Continuous application of inorganic fertilizers increases productivity but soil fertility status is generally reduced whereas, the combined application of organic manures and chemical fertilizer regulate quality; improve crop yield and physical environment of soil. Therefore, the effect of FYM and gliricidia green leaf manuring on some of the chemical properties of soil under cotton + greengram intercropping were recorded and discussed as under. The data on various chemical properties of soil *viz.,* pH and EC content as influenced by various treatments are presented in Table 7.

4.3.1 pH

The negative logarithm of hydrogen ion activity which indicates the acidity or alkaline nature of soil is usually expressed as pH value. The data presented in Table 7 indicate that the pH of soil ranged from 7.91 to 8.20, indicating that soil was moderately alkaline in reaction. The treatment wise variation in pH was found to be significant. The higher value of pH (8.20) was recorded in control treatment (T_1). The lowest pH (7.91) was recorded with the application 50% N ha^{-1}gliricidia + 50% N fertilizers + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6) and it was found to be on par with application of 100% N ha^{-1}gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_8), application of 50% N ha^{-1} FYM + 50% N fertilizers + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_7), application of 50% N ha^{-1} FYM (T_5) and application of 50% N ha^{-1} gliricidia (T_4). The lower value of pH in integrated nutrient management treatments may be due to application of organics which produce organic acids, thereby reduce the pH of soil.

Decrease in pH may be due to organic matter added with gliricidia green leaf manuring which acts as a pH buffer, releasing H^+ which is responsible for reducing alkalinity of the soil. Similar results were also reported

by Pothare *et al.* (2007) and Kumar *et al.* (2008).

Table 7. **Effect of long term INM treatments on pH and EC of soil**

Treatments		pH (1:2.5)	EC(dS m^{-1})
T_1	Control	8.20	0.32
T_2	100% RDF	8.10	0.31
T_3	50% RDF	8.10	0.31
T_4	50% N ha^{-1}gliricidia	8.05	0.29
T_5	50% N ha^{-1} FYM	8.04	0.29
T_6	50% N fertilizers + 50% N ha^{-1}gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	7.91	0.27
T_7	50% N fertilizers + 50% N ha^{-1} FYM + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	7.94	0.27
T_8	100% N ha^{-1}gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	7.92	0.26
SE (m) ±		0.05	0.01
CD at 5%		0.16	0.03

4.3.2 Electrical conductivity

The electrical conductivity is a measure of soluble salt concentration in soil. Higher amount of salts in the soil restrict the nutrient uptake and thus affect the plant growth. The data in respect of electrical conductivity of soil was found to be statistically significant and it ranged from 0.26 to 0.32 dS m^{-1}. However, the data indicated that the lower value of electrical conductivity (0.26 dS m^{-1}) was observed with application of 100% N ha^{-1}gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_8) and it was on par with application of 50% N ha^{-1}gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6), application of 50% N ha^{-1} FYM + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_7), application of 50% N ha^{-1}gliricidia (T_4) and application of 50% N ha^{-1} FYM (T_5).

The higher value (0.32 dS m^{-1}) of electrical conductivity was recorded in treatment T_1 *i.e.* control. Similar results were also reported by Pothare *et al.* (2007) and Gayatri *et al.* (2010).

4.4 Soil fertility

The data in respect of organic carbon (Table 8) and available nutrient status of soil are presented in the Table 9. The data showed the increasing effect of all treatments over control in respect of the organic carbon, available N, P and K content of the soil over the years. Before the start of the experiment in 1987-88, the organic carbon content of the experimental field was 0.46 % and available N, P and K content of soil was 214.0, 12.97 and 316.8 kg ha^{-1}, respectively. After 33rd cycle of the experimentation there was build up in soil fertility with INM treatments.

4.4.1 Organic carbon

The experimental results presented in Table 8 and depicted in Fig 7 indicates that, there was a build up of organic carbon status of soil under cotton + greengram intercropping system in all treatments excluding control over the initial status (0.46%).

Table 8. Effect of long term INM treatments on organic carbon in soil

Treatments		**OC (%)**
T_1	Control	0.45
T_2	100% RDF	0.61
T_3	50% RDF	0.53
T_4	50% N ha^{-1}gliricidia	0.60
T_5	50% N ha^{-1} FYM	0.61
T_6	50% N fertilizers + 50% N ha^{-1}gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	0.73
T_7	50% N fertilizers + 50% N ha^{-1} FYM + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	0.72
T_8	100% N ha^{-1}gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	0.69
SE (m) ±		0.02
CD at 5%		0.07

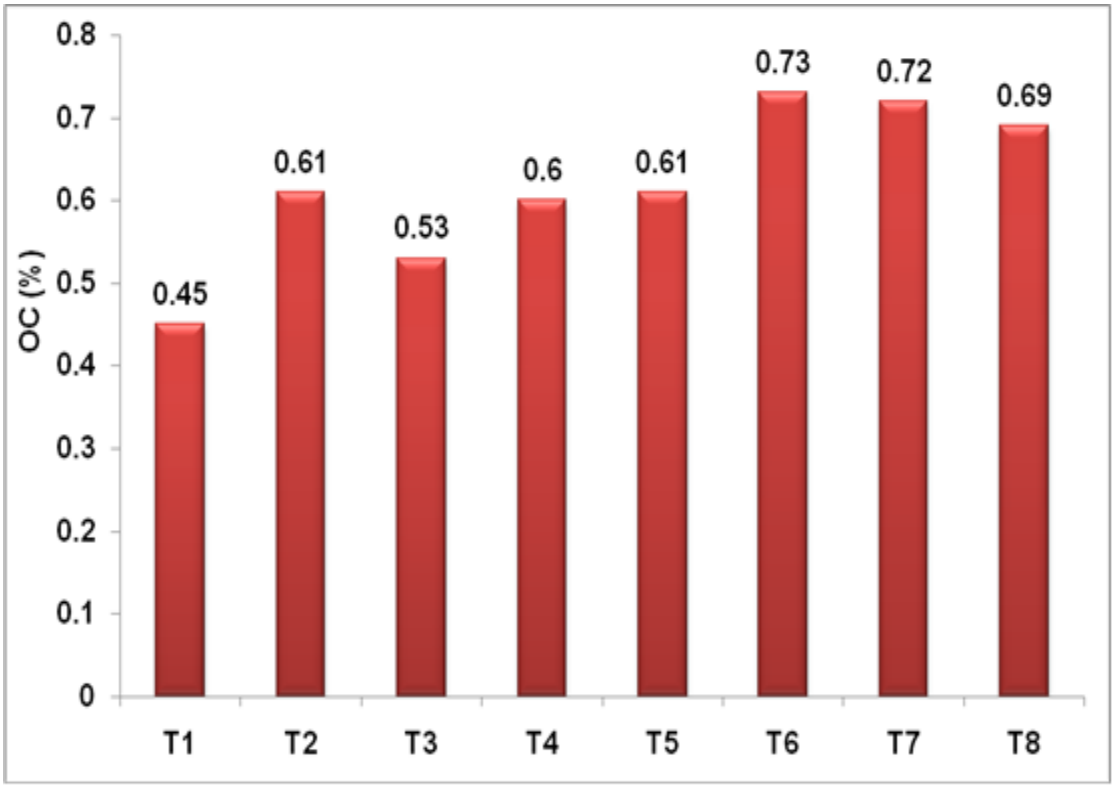


Fig 7. Effect of long term INM treatments on organic carbon in soil

The treatments which received organic matter through FYM and

green leaf manuring of gliricidia lopping recorded improvement in the organic carbon content of the soil over control. However, highest 0.73% soil organic carbon was recorded in treatment 50% N ha^{-1} gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6) followed by 0.72% organic carbon content in 50% N ha^{-1} FYM + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_7) and 100% N ha^{-1}gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_8) which were found to be on par with each other. The lower value (0.45%) of organic carbon was found in treatment T_1 *i.e.* control.

The higher values of organic carbon content with application of gliricidia and FYM green leaf manuring may be attributed to addition of organic materials and greater root biomass with their addition as evidenced from the higher yields obtained in these treatments. Application of organic sources and/ or combination with chemical fertilizer helped for building up of organic carbon. Similar results were also reported by Regar *et al.* (2009), Sharma *et al*. (2011) and Tamboli *et al*. (2013).

4.3.2 Organic carbon balance

The data in respect of organic carbon balance depicted in Fig 8 indicate the higher gain of 0.27% in treatment 50% N ha^{-1} gliricidia + 50% + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6) followed by treatments 50% N ha^{-1} FYM + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_7) and 100% N ha^{-1} gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_8).

Soil, water and temperature are the limiting factors of the dryland agriculture and have direct influence on the soil organic carbon. Natural incorporation of the crop residues in to the soil after harvest of the crop is common phenomenon, but year after year, continuous addition of the crop residues or green manuring or even FYM has a very little effect on soil organic carbon in dryland condition. The data of long-term experimentation showed the improvement and maintenance of the soil organic carbon content in dryland agriculture as a result of judicious use of gliricidia green leaf manure and well decomposed FYM in combination with the inorganic fertilizers. Use of organic or inorganic plant nutrient sources alone was not helpful in significant build up of organic carbon in soils under dryland

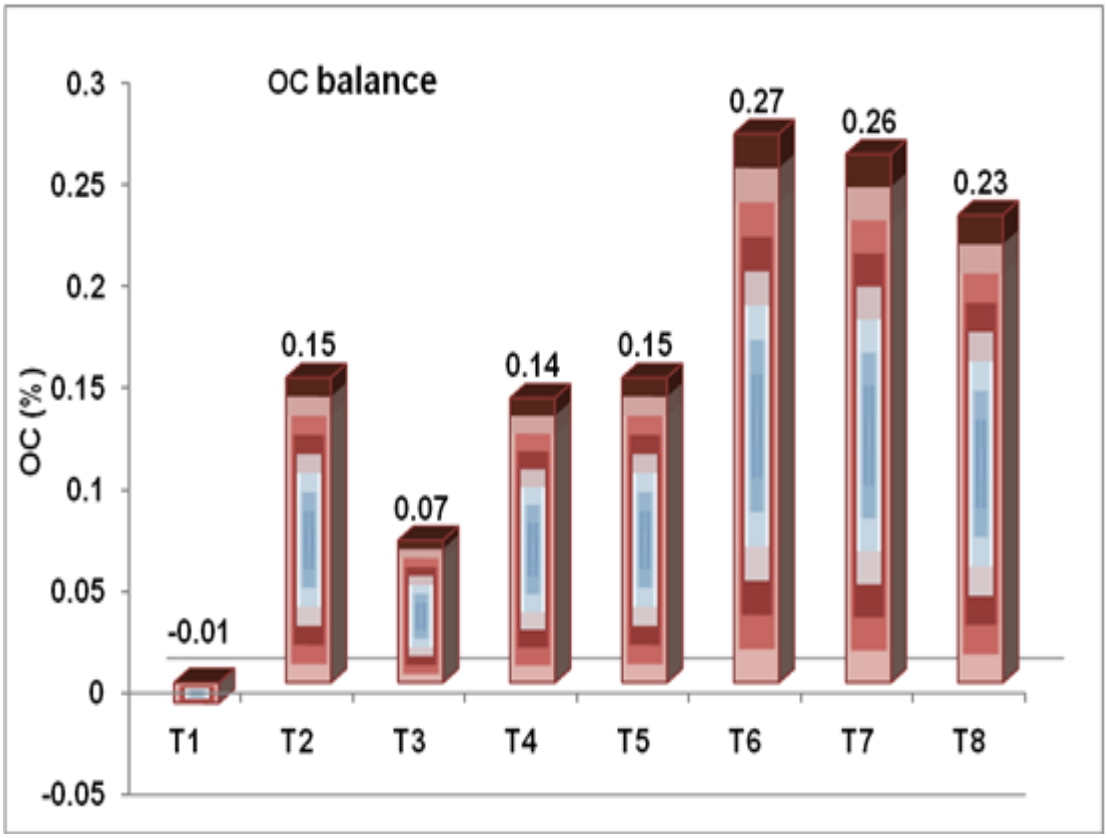


Fig 8. Effect of long term INM treatments on organic carbon balance

condition.

4.4.2 Available Nitrogen

The data (Table 9 & Fig 9) on available nitrogen status of the experimental soil, indicated that significantly higher available nitrogen (261.33 kg ha^{-1}) was observed in treatment T_6 (50% N ha^{-1} gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers) which was on par (259.24 kg ha^{-1}) with application of 50% N ha^{-1} FYM + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_7) and treatment (T_8) application of 100% N ha^{-1}gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (252.97 kg ha^{-1}). It was also noted that 28.7% and 10.6% increase in available N content was recorded with application of 50% N ha^{-1} gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6) as compared to control (T_1) and 100 % RDF (T_2), respectively. The lowest available nitrogen (202.79 kg ha^{-1}) was observed in absolute control (T_1).

The higher value of available N over the initial value might be due to nitrogen fixation by greengram crop. The favourable soil conditions under gliricidia/FYM addition might have helped in mineralization of soil N leading to build up of higher available N. Similar results were also reported by Shirale and Khating (2009), Deshmukh *et al.* (2011), Gabhane *et al*. (2013), Naik (2016) and Chandel *et al*. (2017).

4.4.3 Available Phosphorus

In general, the data indicate that the treatments (T_6 & T_7) which received 50% N fertilizers + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers with 50% N either through gliricidia lopping or FYM recorded higher content of available phosphorus over all other treatments. The maximum 18.59 kg ha^{-1} available phosphorus was recorded in treatment 50% N ha^{-1} gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6) and was on par (17.25 kg ha^{-1}) with treatment application of 50% N ha^{-1} FYM + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_7).

It was also noted that 72.9% and 11% increase in available phosphorus content was recorded with application of 50% N ha^{-1} gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6) as compared to control (T_1) and 100% RDF (T_2), respectively. The lowest 10.75 kg ha^{-1} available P was

observed in control treatment.

The increase in available phosphorus status is due to use of gliricidia/FYM, being direct source of phosphorus and it might have also solubilized the native phosphorus in the soil through release of various organic acids which had chelating effect, that reduced phosphorus fixation. The higher values of available phosphorus in treatment T_6 and T_7 may be due to addition of phosphorus through FYM/ gliricidia in soil. Similar results were recorded by Vaiyapuri *et al.*(2008), Regar *et al*. (2009), Shirale and Khating (2009) ,Vidyavathi *et al*. (2011) and Naik (2016).

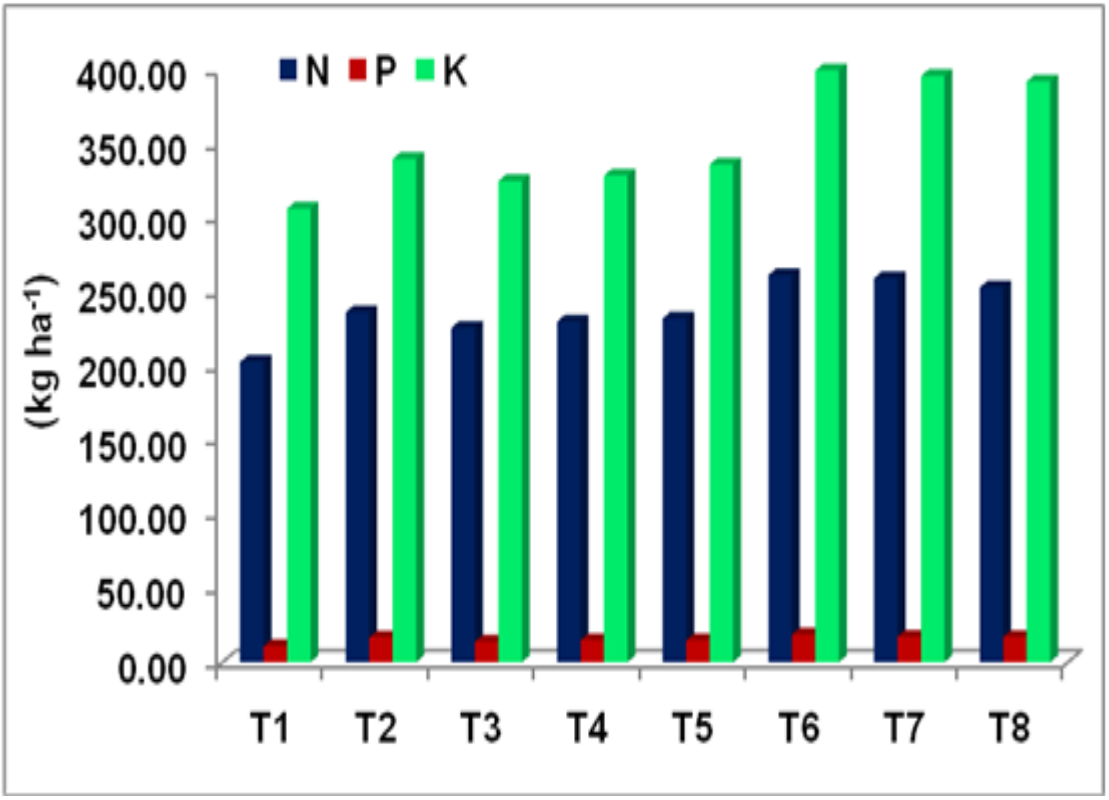
Table 9. Effect of long term INM treatments on soil fertility

Treatments		Available Nutrients (kg ha^{-1})		
		N	P	K
T_1	Control	202.79	10.75	306.13
T_2	100% RDF	236.25	16.73	339.73
T_3	50% RDF	225.79	13.81	324.80
T_4	50% N ha^{-1}gliricidia	229.97	14.86	328.53
T_5	50% N ha^{-1} FYM	232.06	14.78	336.00
T_6	50% N fertilizers + 50% N ha^{-1}gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	261.33	18.59	399.47
T_7	50% N fertilizers + 50% N ha^{-1} FYM + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	259.24	17.25	395.73
T_8	100% N ha^{-1}gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	252.97	17.02	392.00
SE (m) ±		5.47	0.60	18.94
CD at 5%		16.27	1.79	56.27
Initial(1987-88)		214	12.97	316.8

4.4.4 Available Potassium

The black soils developed from basalt have the major quantity of the mineral feldspar which is rich in K, Na and Ca, hence potash fertilizers are not recommended for the crops grown on black soils. The swelling and shrinkage property of black clayey soils trap the K ions in crystal lattice. The

Fig 9. Effect of long term INM treatments on available nutrients in soil



data on available potassium status of the experimental soil, indicated that significantly higher available potassium (399.47 kg ha^{-1}) was observed in treatment T_6 (50% N ha^{-1} gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers), followed by treatment (T_7) application of 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through Urea, SSP & MOP in combination with 50% N ha^{-1} through FYM (395.73 kg ha^{-1}) and 100% N ha^{-1} gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (392.00 kg ha^{-1}). It was also noted that 30.5% and 17.6% increase in available K content was recorded with application of 50% N ha^{-1} gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6) as compared to control (T_1) and 100 % RDF (T_2), respectively. The lowest available potassium (306.13 kg ha^{-1}) was observed in absolute control (T_1).

In general, the treatments (T_6 & T_7) which received gliricidia lopping/FYM in combination with fertilizers showed better performance in respect of available potassium over all other treatments. Thus, the results indicate that to exploit the inherent potential available potash supplying capacity of black soil, application of the FYM/gliricidia in combination with the inorganic fertilizers is necessary.

Thus, from the data, it is revealed that, application 50% N + 100% P_2O_5 ha^{-1} + 100% K_2O ha^{-1} through urea, SSP and MOP + 50% N ha^{-1} through gliricidia/FYM resulted in build up of soil fertility. The build up of soil available K by the application of potassium through gliricidia green leaf manuring and FYM might be due to the fact that gliricidia leaves contains higher amount of K and it is deposited in the soil and due to applied K through gliricidia green leaf manure, the solubilizing action of certain organic acids produced during decomposition results in greater capacity to hold K in the available form. Similar results were observed by Shirale and Khating (2009), Wagh *et al.* (2016), Naik *et al.* (2018) and Satpute *et al.* (2019).

4.4.5 Nutrient balance

The data on nutrient (N, P & K) balance as influenced by various treatments are presented in Table 10 and depicted in Fig 10.

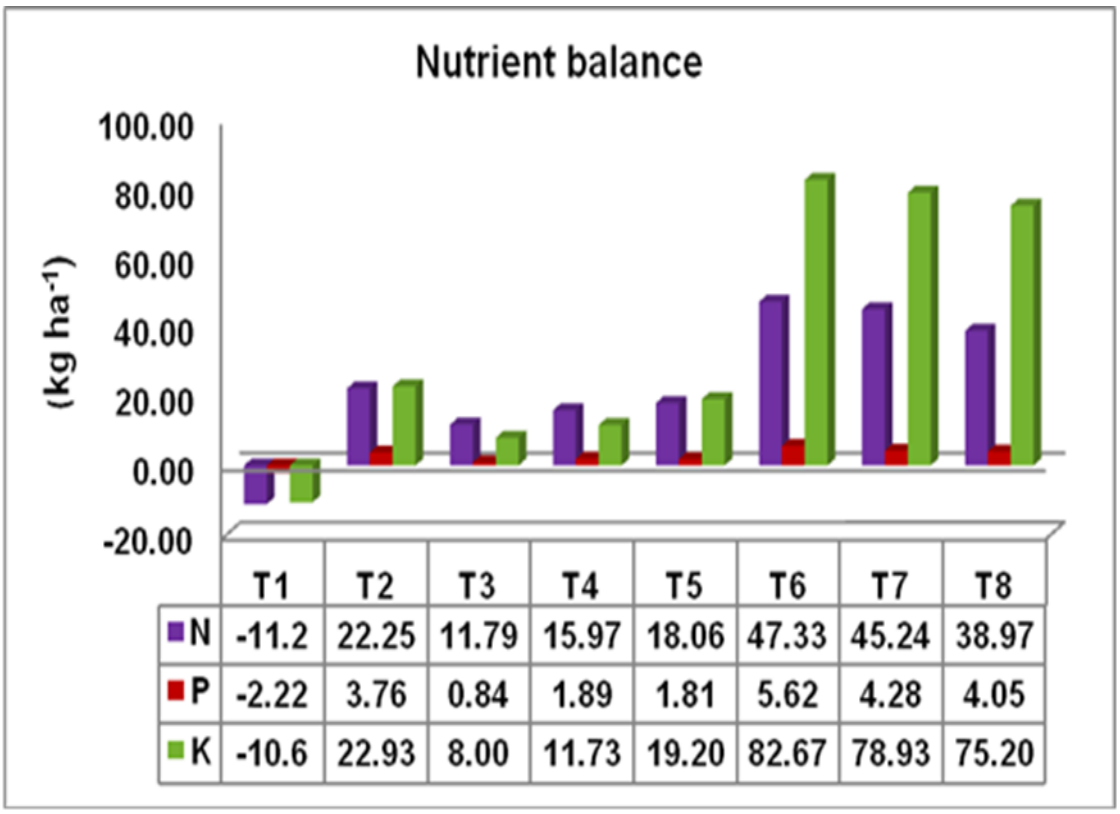
Table 10. Effect of long term INM treatments on nutrient balance in cotton+ greengram intercropping system

Treatment	Nutrient status at the end (2019-20) (kg ha^{-1})			Net gain(+)/Loss(-) (kg ha^{-1})		
	N	P	K	N	P	K
T_1	202.79	10.75	306.13	-11.2	-2.2	-10.7
T_2	236.25	16.73	339.73	22.2	3.8	22.9
T_3	225.79	13.81	324.80	11.8	0.8	8.0
T_4	229.97	14.86	328.53	16.0	1.9	11.7
T_5	232.06	14.78	336.00	18.1	1.8	19.2
T_6	261.33	18.59	399.47	47.3	5.6	82.7
T_7	259.24	17.25	395.73	45.2	4.3	78.9
T_8	252.97	17.02	392.00	39.0	4.1	75.2
Initial	214	12.97	316.8	-	-	-

The data in respect of nitrogen balance indicate the gain of nitrogen in all the treatments except control. However, the higher gain of nitrogen (47.3 kg ha^{-1}) was recorded with application of 50% N ha^{-1} gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6) followed by 45.2 kg ha^{-1} with application of 50% N ha^{-1} FYM + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_7). The results revealed that, the combined use of nitrogen sources *i.e.* fertilizer and organic matter is essential for improvement in available N content of soil.

The data in respect of phosphorus balance indicate the gain of phosphorus in the treatments where gliricidia and FYM were used as organic sources in combination with inorganic fertilizers. However, the higher gain of phosphorus (5.6 kg ha^{-1}) was recorded in treatment T_6 followed by T_7 (4.3 kg ha^{-1}).

The data in respect of potassium balance indicate the gain of potassium in all the treatments except control. However higher gain of potassium (82.7 kg ha^{-1}) was recorded with application of 50% N ha^{-1} gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6) followed by 78.9 kg



	T1	T2	T3	T4	T5	T6	T7	T8
N	-11.2	22.25	11.79	15.97	18.06	47.33	45.24	38.97
P	-2.22	3.76	0.84	1.89	1.81	5.62	4.28	4.05
K	-10.6	22.93	8.00	11.73	19.20	82.67	78.93	75.20

Fig 10. Effect of long term INM treatments on nutrient balance in soil

ha^{-1} with application of 50% N ha^{-1} FYM + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_7). The higher gain was noticed where gliricidia and FYM were used as organic sources in combination with inorganic fertilizers.

4.5 Potassium fractions in soil

The availability of potassium to plant depends on relative mobility of the different forms of K in soil. A knowledge regarding the various forms of K in soil and the condition controlling its availability to cotton and greengram crop is important for the appraisal of the available potassium. Therefore, it is necessary to study the transformation of applied K in different forms and their influence on the yield of cotton + greengram intercropping system in Vertisols.

Data pertaining to distribution of various potassium fractions *viz*., water soluble (WSK), exchangeable (EX- K), non-exchangeable (NEK), lattice K (LK) and total K (TK) are presented in Table 11 and graphically depicted in Fig 11 and per cent contribution of different potassium fractions to total K are presented in Table 12 and graphically depicted in Fig 12.

4.5.1 Water soluble potassium

Soil solution K is the form of K that is directly taken up by plants and microbes and also is the form subject to most leaching in soil. Data pertaining to distribution of water soluble (WSK) are presented in Table 11 and graphically depicted in Fig 11.

The effect of integrated nutrient management on water soluble potassium was significant. Significantly higher water soluble potassium (23.67 mg kg^{-1}) was recorded with the application of application of 50% N ha^{-1} gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6) and it was on par with application of 50% N ha^{-1} FYM + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_7). It was also noted that 61.3 % and 14.5% increase in water soluble potassium content was observed with application of 50% N ha^{-1} gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6) as compared to control (T_1) and 100 % RDF (T_2), respectively. The lowest water soluble potassium (14.67 mg kg^{-1}) was recorded in control treatment (T_1).

This might be due to the fact that gliricidia leaves contains higher

amount of K and it is deposited in the soil and due to applied K through gliricidia green leaf manure, the solubilizing action of certain organic acids produced during decomposition results in greater capacity to hold K in the available form. These results are in agreement with the findings of Sharma and Verma (2000), Singh *et al*. (2005), Babar *et al*. (2007), Singh *et al.* (2014), Sujatha *et al.* (2017) and Yadav *et al*. (2019).

4.5.2 Exchangeable potassium

Exchangeable K has been generally regarded as reliable index of K removal by crops. It is held by virtue of the negative charges of organic matter and clay minerals in soil. It is easily exchanged with other cations and is relatively easily available to plants. Data pertaining to distribution of exchangeable potassium is presented in Table 11 and graphically depicted in Fig. 11.

The effect of integrated nutrient management on exchangeable potassium was found to be significant. Significantly highest exchangeable potassium (336.00 mg kg^{-1}) was recorded with the application 50% N ha^{-1} gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6) and it was on par with application of 50% N ha^{-1} FYM + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_7) and application of 100% N ha^{-1} gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_8) as well as with 100% RDF (T_2) and 50% N ha^{-1} FYM (T_5). It was also noted that 57.9% and 7.1% increase in exchangeable potassium content was observed with application of 50% N ha^{-1} gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6) as compared to control (T_1) and 100 % RDF (T_2), respectively. The lowest exchangeable potassium (212.80 mg kg^{-1}) was recorded in control treatment (T_1). The higher amount of exchangeable K in the green leaf manure treated plots over the years can be attributed to the fact that green leaf manure addition could increase the CEC of soil which was responsible for holding more amount of exchangeable K and helped in the release of exchangeable K from non-exchangeable K.

These results are in agreement with the findings of Babar *et al*. (2007), Singh *et al.* (2014), Sujatha *et al.* (2017) and Yadav *et al*. (2019).

4.5.3 Non-exchangeable potassium

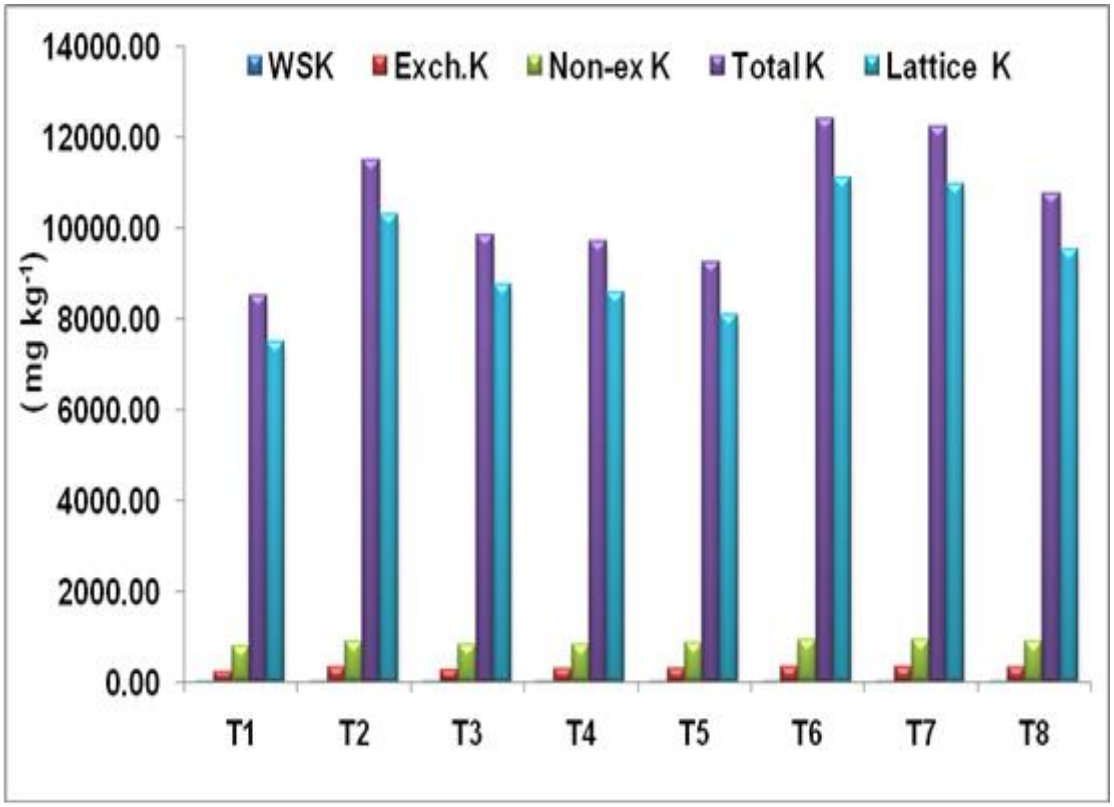
Non-exchangeable potassium is held between adjacent tetrahedral layers of dioctahedral and trioctahedral micas, vermiculites and intergrade clay minerals. It is also found in wedge zones of weathered micas and vermiculites. Non-exchangeable K is moderately to sparingly available to plants. Data pertaining to distribution of non-exchangeable potassium in soil is presented in Table 11 and graphically depicted in Fig 11.

Table 11. Long term effect of INM on potassium fractions in soil

Treatment		WSK	Exch. K	Non-Ex K	Total K	Lattice-K
		(mg kg^{-1})				
T_1	Control	14.67	212.80	776.67	8512.0	7507.9
T_2	100% RDF	20.67	313.60	876.67	11498.7	10287.7
T_3	50% RDF	18.33	257.60	820.00	9856.0	8760.1
T_4	50% N ha^{-1}gliricidia	17.33	283.73	826.67	9706.7	8578.9
T_5	50% N ha^{-1} FYM	19.00	306.13	860.00	9258.7	8073.5
T_6	50% N fertilizers + 50% N ha^{-1}gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	23.67	336.00	923.33	12394.7	11111.7
T_7	50% N fertilizers + 50% N ha^{-1} FYM + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	22.33	328.53	916.67	12245.3	10977.8
T_8	100% N ha^{-1}gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	19.67	313.60	880.00	10752.0	9538.7
	SE (m) ±	0.68	15.55	9.77	261.71	264.17
	CD at 5%	2.03	46.21	29.03	777.62	784.93

The effect of integrated nutrient management on non-exchangeable potassium was significant. Significantly highest non-exchangeable potassium (923.33 mg kg^{-1}) was recorded with the application 50% N ha^{-1} gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6) and it was on par with application of 50% N ha^{-1} FYM + 50% N + 100% P_2O_5 +

Fig 11. Effect of long term INM treatments on potassium fractions in soil



100% K_2O ha^{-1} fertilizers (T_7). It was also noted that 18.9% and 5.3% increase in non-exchangeable potassium content was observed with application of 50%

N ha^{-1} gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6) as compared to control (T_1) and 100 % RDF (T_2), respectively. The lowest non-exchangeable potassium (776.67 mg kg^{-1}) was recorded in control treatment (T_1). Sawarkar *et al.* (2013) while studying distribution of potassium fractions also reported the non-exchangeable potassium in the range of 736 to 885 mg kg^{-1} in Vertisols.

These results are in agreement with the findings of Pannu *et al.* (2001), Babar *et al*. (2007), Singh *et al.* (2014) and Yadav *et al*. (2019).

4.5.4 Lattice potassium

It is fraction of K that gets fixed in lattice space of 2:1 clay minerals. This form of K is distinct form of mineral K in that, it is not bonded covalently within the crystal structure of soil mineral particle but held between adjacent tetrahedral layers of dioctahedral and trioctahedral wedge zones of weathered micas and vermiculite. Data pertaining to distribution of lattice potassium is presented in Table 11 and graphically depicted in Fig 11.

The effect of integrated nutrient management on lattice potassium was significant. Significantly highest lattice potassium (11111.7 mg kg^{-1}) was recorded with the application 50% N ha^{-1} gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6) and it was on par with application of 50% N ha^{-1} FYM + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_7). It was also noted that 48% and 8% increase in lattice potassium content was observed with application of 50% N ha^{-1} gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6) as compared to control (T_1) and 100 % RDF (T_2), respectively. The lowest lattice potassium (7507.9 mg kg^{-1}) was recorded in control treatment (T_1).

The increased lattice-K content maintained under a long term integrated nutrient management might be due to the addition of gliricidia green leaf manure which have larger amount of potassium content. Similar results were also noted by Babar *et al*. (2007), Jadhao *et al.* (2015) and Yadav *et al*. (2019).

4.5.6 Total potassium

The knowledge of K fertility status is of prime importance as it

indicates the total reserve of K which may become available to plants. More than 90 per cent of total K in soil is within the crystal lattice of silicate minerals, which on weathering slowly releases K in soil for plant utilization. Data pertaining to distribution of total potassium is presented in Table 11 and graphically depicted in Fig 11.

The effect of integrated nutrient management on total potassium was significant. Significantly highest total potassium (12394.7 mg kg^{-1}) was recorded with the application 50% N ha^{-1} gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6) and it was on par with application of 50% N ha^{-1} FYM + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_7). It was also noted that 45.6% and 7.8% increase in total potassium content was observed with application of 50% N ha^{-1} gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6) as compared to control (T_1) and 100 % RDF (T_2), respectively.

The lowest total potassium (8512.0 mg kg^{-1}) was recorded in control treatment (T_1).

The combined application of manures and fertilizers (NPK+GLM, FYM) resulted in larger amount of SOC which adds additional amount of K and also provide sorption site for K on application of organic manure along with mineral fertilizer. These results are in agreement with the findings of Singh *et al.* (2014), Jadhao *et al*. (2015) and Yadav *et al*. (2019).

4.6 Contribution of different potassium fraction to total K

The different potassium fractions were analyzed and contribution of each fraction was calculated against total K in percent. The data of the same is presented in Table 12 and graphically depicted in Fig 12.

Table 12. Contribution of different potassium fractions to total K

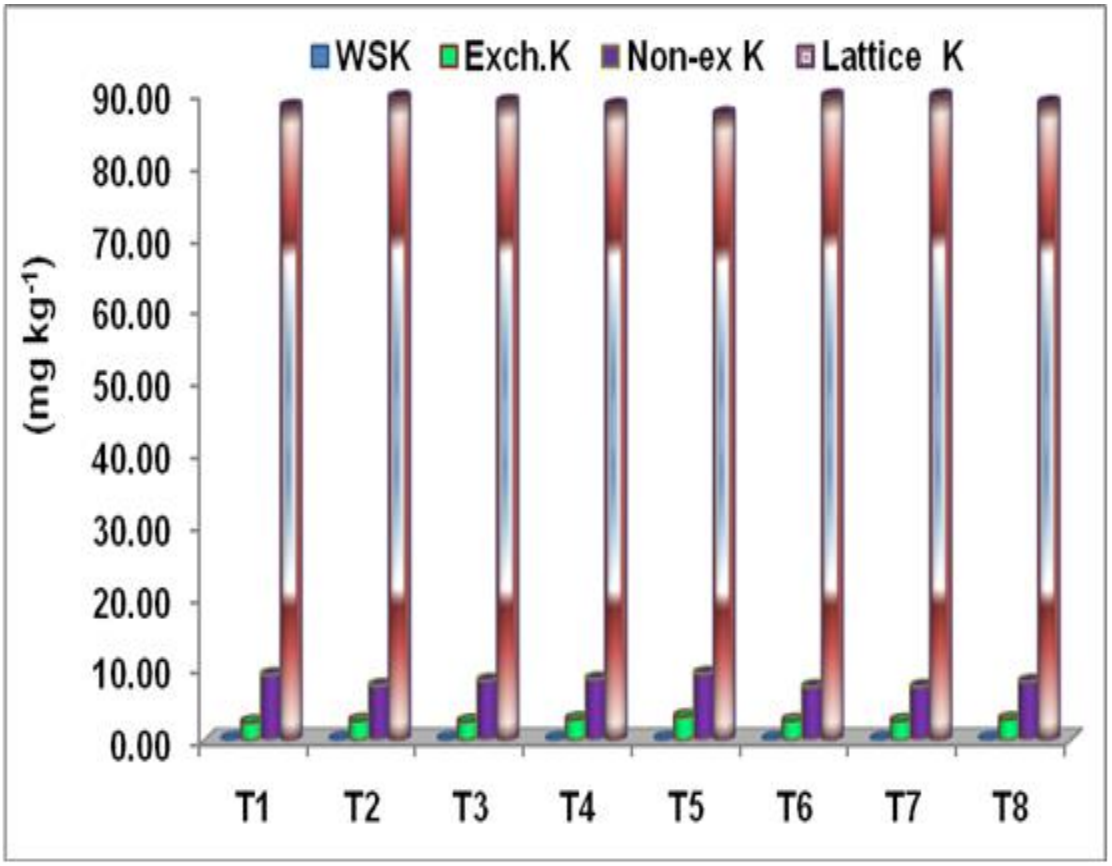
% of Total K					
Treatments		**WSK**	**Exch.K**	**Non-ex K**	**Lattice K**
T_1	Control	0.17	2.50	9.12	88.20
T_2	100% RDF	0.18	2.73	7.62	89.47
T_3	50% RDF	0.19	2.61	8.32	88.88
T_4	50% N ha^{-1}gliricidia	0.19	2.92	8.52	88.38
T_5	50% N ha^{-1} FYM	0.18	3.31	9.29	87.20
T_6	50% N fertilizers + 50% N ha^{-1}gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	0.21	2.71	7.45	89.65
T_7	50% N fertilizers + 50% N ha^{-1} FYM + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	0.19	2.68	7.49	89.65
T_8	100% N ha^{-1}gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers	0.18	2.92	8.18	88.72

The data indicated the higher contribution of lattice K to total K (87.20 % to 89.65 %) indicating dominant K fraction which contributed substantially to total K. Among all the fractions, water soluble (WSK) potassium contributed less *i.e.* between 0.17- 0.21%. Across different treatments the contribution of exchangeable K and non-exchangeable K towards total K under different treatments was in the range 2.50 - 3.31 % and

7.45 - 9.29 %, respectively.

The contribution of non-exchangeable K to total K indicate that, this form appreciably contributed to total pool indicating fixation of potassium in the interlayer, which suggest the need of application of organics, which help in release of K. The inclusion of green manure or FYM along with chemical fertilizers was found beneficial in improving the non-exchangeable K status of soil. These results are in agreement with the findings of Swapana *et al.* (2012), Jadhao *et al*. (2016) and Yadav *et al*. (2019).

Fig 12. Contribution of potassium fractions to total potassium



4.6 Correlation among yield and various potassium fractions

The data on correlation among seed cotton yield and potassium

fractions are presented in Table 13. The seed cotton yield was significantly and positively correlated with all the potassium fractions. The coefficient of correlation ranged between 0.650** to 0.852**. The exchangeable K (r=0.852**) was highly correlated with seed cotton yield.

The data on correlation among greengram yield and potassium fractions are presented in Table 13. The greengram yield was significantly and positively correlated with all the potassium fractions. The coefficient of correlation ranged between 0.598** to 0.850**. The lattice K (r=0.850**) was highly correlated with greengram yield.

The data on correlation among seed cotton equivalent yield (SCEY) and potassium fractions are presented in Table 13. The SCEY yield was significantly and positively correlated with all the potassium fractions. The coefficient of correlation ranged between 0.671** to 0.882**. The exchangeable K (r=0.882**) was highly correlated with seed cotton equivalent yield.

Table 13. Correlation among crop yield and various potassium fractions

	Seed cotton yield	**Greengram yield**	**Seed cotton equivalent yield(SCEY)**
Yield	1.000	1.000	1.000
WSK	0.806**	0.745**	0.833**
Exch. K	0.852**	0.792**	0.882**
Nonex K	0.650**	0.598**	0.671**
Lattice K	0.764**	0.850**	0.848**
Total K	0.777**	0.846**	0.838**

** Significant at 1% level of significance

4.6.1 Correlation among various potassium fractions

The correlation among various potassium fractions indicated that, all the K fractions showed significant and positive correlation with water soluble K indicating rapid establishment of equilibrium between these forms.

T_1 Control

T_2 100 % RDF

T_6 50% N fertilizers + 50% N ha^{-1}gliricidia +100% P_2O_5+ 100% K_2O ha^{-1} fertilizers

T_7 50% N fertilizers + 50% N ha^{-1} FYM + 100% P_2O_5+ 100% K_2O ha^{-1} fertilizers

Table 14. Correlation among various potassium fractions

	WSK	Exch. K	Nonex K	Lattice K	Total K
WSK	1.000				
Exch. K	0.746**	1.000			
Nonex K	0.885**	0.713**	1.000		
Lattice K	0.810**	0.665**	0.805**	1.000	
Total K	0.825**	0.689**	0.823**	0.999**	1.000

** Significant at 1 % level of significance

Comparatively high degree of correlation of Total K with Lattice K (r=0.999**) followed by water soluble K with non exchangeable K (r=0.885**) showed rapid establishment of equilibrium between these forms. Similar type of correlation was reported by Ravankar *et al*. (2001), Babar *et al*. (2007), Swapana *et al.* (2012), Jadhao *et al*. (2015) and Yadav *et al*. (2019).

CHAPTER V

SUMMARY AND CONCLUSIONS

The present investigation entitled “Long term effect of integrated nutrient management on soil fertility, potassium fractions and yield of cotton + greengram (1:1) intercropping system in Vertisols”, was conducted during *kharif* 2019-20 at research field of AICRP for Dryland Agriculture, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola with eight treatments laid out in Randomized Block Design with three replications, in order to study the long term effect of integrated nutrient management on soil fertility, potassium fractions and yield of cotton + greengram intercropping system in Vertisols.

The soil samples were collected plot wise after harvest of cotton crop and analyzed for various physical and chemical properties and various potassium fractions in soil. The cotton + greengram yield was also recorded. The salient findings of the present investigation can be shortly summarized as under.

5.1 Yield of cotton + greengram (1:1) intercropping system

Long term application of 50% RDN through organic source *i.e.* FYM in combination with 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through inorganics (T_7) recorded significantly higher seed cotton yield (776.3 kg ha^{-1}) and was on par with the application of 50% N through gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through fertilizers (T_6), application of 100% RDF (T_2) and application of 100% N through gliricidia + 100% P_2O_5 + 100% K_2O ha^{-1} through fertilizers (T_8).The increase in seed cotton yield with long term application of 50% RDN through organic source *i.e.* FYM in combination with 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through inorganics (T_7) was 82.8 % and 11.8 % higher as compared to control (T_1) and 100 % RDF (T_2) treatments, respectively.

Significantly higher cotton stalk yield (1527.7 kg ha^{-1}) was recorded with long term application of 50% RDN through organic source *i.e.* FYM in combination with 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through inorganics (T_7) and was on par with the application of 50% N ha^{-1} through gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through fertilizers (T_6) and application of 100% RDF (T_2).

Long term application of 50% RDN through organic source *i.e.* FYM in combination with 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through inorganics (T_7) recorded significantly higher greengram grain yield (286.2 kg ha^{-1}) and was on par with the application of 50% N through gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through fertilizers (T_6). The increase in greengram grain yield with long term application of 50% RDN through organic source *i.e.* FYM in combination with 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through inorganics (T_7) was 118.6 % and 26.5 % higher as compared to control (T_1) and 100 % RDF (T_2) treatments, respectively.

The application of 50% RDN through organic source *i.e.* FYM in combination with 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through inorganics (T_7) recorded significantly higher greengram straw yield (178.6 kg ha^{-1}) and was on par with the application of 50% N through gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through fertilizers (T_6).

Long term application of 50% RDN through organic source *i.e.* FYM in combination with 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through inorganics (T_7) recorded significantly higher seed cotton equivalent yield (1386.5 kg ha^{-1}) and was on par with the application of 50% N through gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through fertilizers (T_6).The increase in seed cotton equivalent yield with long term application of 50% RDN through organic source *i.e.* FYM in combination with 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} through inorganics (T_7) was 92.2% and 15.8% higher as compared to control (T_1)and 100 % RDF (T_2) treatments, respectively.

The Rainwater use efficiency (RWUE) for cotton (0.85 kg $ha^{-1}mm^{-1}$), greengram (0.35 kg $ha^{-1}mm^{-1}$) and seed cotton equivalent yield (1.21 kg $ha^{-1}mm^{-1}$) were higher under integrated nutrient management involving use of chemical fertilizers with FYM (T_7) which was followed by 50% N ha^{-1} gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6).

5.2 Physical properties of soil

The data pertaining to the bulk density of soil as influenced by various treatments was statistically significant and it ranged from 1.40 to 1.46 Mg m^{-3}, indicating that the lowest bulk density (1.40 Mg m^{-3}) was recorded with the application of 50% N ha^{-1} gliricidia + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1} fertilizers (T_6) and 50% N ha^{-1} FYM + 50% N + 100% P_2O_5 + 100% K_2O ha^{-1}

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