

**AGRONOMIC MANIPULATIONS FOR PRODUCTIVITY
AND INCOME ENHANCEMENT IN *Melia dubia* Cav.
BASED AGROFORESTRY SYSTEM UNDER
ORGANIC PRODUCTION**

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AND INCOME ENHANCEMENT IN *Melia dubia* Cav.
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ORGANIC PRODUCTION**

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by

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C E R T I F I C A T E

This is to certify that the thesis entitled “**AGRONOMIC MANIPULATIONS FOR PRODUCTIVITY AND INCOME ENHANCEMENT IN *Melia dubia* Cav. BASED AGROFORESTRY SYSTEM UNDER ORGANIC PRODUCTION** ” submitted by **SHYAMRAO KULKARNI** for the degree of **DOCTOR OF PHILOSOPHY (AGRICULTURE)** in **AGRONOMY**, College of Agriculture, Raichur, University of Agricultural Sciences, Raichur, is a record of research work carried out by him during the period of his study in this University under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

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AFFECTIONATELY DEDICATED

TO

FARMERS,

MY BELOVED KULKARNI'S

FAMILY MEMBERS

AND

TEACHERS

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With regardful memories.....

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LIST OF ABBREVIATIONS

Abbreviation	Expansion
cf	: Contra factum (see)
%	: Per cent
°C	: Degree centigrade
π	: Pie
B:C	: Benefit cost ratio
C	: Carbon
cm	: Centimeter
DAS	: Days After Sowing
DBH	: Diameter at breast height
GBH	: Girth at breast height
MAP	: Months after planting
dS m ⁻¹	: Decisiemens per meter
<i>et al</i>	: Etalia (Coworkers)
EC	: Electrical conductivity
Fig.	: Figure
g	: Gram
ha	: Hectare
K	: Potassium
kg	: Kilogram
LAI	: Leaf area index
m	: Meter
mm	: Millimeter
N	: Nitrogen
P	: Phosphorus
q	: Quintal
RH	: Relative humidity
S. Em.±	: Standard Error of Mean
t	: Tonnes
NS	: Not Significant
<i>viz</i>	: Namely

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INTRODUCTION

I. INTRODUCTION

India is the second most populous country in the world. The human population is expected to reach a mark of 1.7 billion, demanding around 333 million tonnes of food grains by 2050 in the country. In parallel, there is also an increasing demand to meet the fodder requirement for cattle which is estimated at 2055 million tonnes. The annual productivity of Indian forests is $1.36 \text{ m}^3 \text{ ha}^{-1}$ compared to the world average of $2.5 \text{ m}^3 \text{ ha}^{-1}$. It is estimated that around 149 million m^3 timber wood would be required annually in India against the projected production of 100 million m^3 by 2050, thus emphasizing a huge gap between demand and supply in future. Besides this, the requirement of fuel and timber are estimated at 250 million tonnes and 350 million cubic metres, respectively (Anon., 2018 a). To fulfill all these needs, the vertical farming is the only solution as there is no scope for increasing area under cultivation. The land is a shrinking resource and the per capita availability of land has decreased from 0.3 ha in 1950 to 0.13 ha in 2015 as a result of increase in human population.

To meet rising population demand for food and timber wood, there is intense pressure on cultivable land and existing forests. The escalating demand of food, fodder and timber wood can be attained either by increasing the farm area or the productivity. Since the former option has limited scope, the only economic and viable option left out for enhancing the productivity of agricultural field is with integration of trees in agroforestry systems. In order to meet the requirement, particularly for wood and tree derived produce, the fast growing species in the present context are playing major role to increase the productivity. On the other hand, the increasing concentration of carbon in the atmosphere is also creating difficulty to the biological entities in the form of climate change which needs to be minimized, where fast growing trees are playing crucial role in carbon sequestration.

The prosperity generated by the green revolution in irrigated areas made the general scarcity of fuel and all the more troublesome. The farmers therefore are in habit of progressive step of planting fast growing trees around their homesteads, along field boundaries, irrigation channels and also within fields. The preferred tree species are *Eucalyptus*, *Poplar*, *Sissoo*, *Neem*, *Subabul* etc., which cast low amount of shade and have least root effect. The cash value realized from sale of trees with in a short period is very high and more than compensates for any marginal adverse effects that planting of

such trees may have on crop yields. The trees normally, do not directly compete with shallow rooted agricultural crops either for water or for nutrients nor do these selected species cast enough shade to be detrimental to the crop growth. On the contrary, trees add significant amount of litter to the soil and enrich it with organic matter and since they absorb nutrients from the lower depths of soil and also aid in recycling the plant nutrients to the top soil. Trees do attract birds, but perhaps the loss in grain is more than compensated by elimination of insect pests. Environmentally and economically, trees are boon to the farmers.

In this context, agroforestry, a concept developed in recent decades, but traditionally practiced in Indian sub-continent and elsewhere as a low cost input farming system, will be of much help to combat the situation. Farming systems that incorporate perennial trees and shrubs have the advantage of producing fuel wood, timber, fodder, fruit and other products along with annual crops. In addition, they decrease the farmers' exposure to seasonal, environmental variations and over the long term, maintain and improve soil health. There are many tree species which are found to be suitable for agroforestry system but recently *Melia dubia* gaining more importance and most preferred.

Melia dubia belongs to Meliaceae family, is a promising tree highly suitable for farm forestry and agroforestry for generating higher income in the semi-arid regions. One of the main problems that farmers are facing today is decreasing income per unit area per unit time as against sudden increase in the value of agricultural lands. Planting certain tree species such as *Melia dubia* which fetches a handsome price in the market with assured buyback with requiring low maintenance expenditure. In addition, the trees also aid the planet by preventing temperature rise and checking gas emission into the atmosphere as the trees are naturally endowed to absorb maximum carbon dioxide. It is good for land rehabilitation and afforestation planting purposes. Its cultivation provides the economic upliftment of farmers (Kannan *et al.*, 2013). Hence, the cultivation and utilization of trees is economically viable, ecologically empathetic, environmentally ameliorative and aesthetically acceptable.

Recently *Melia dubia* tree species has been introduced in north eastern part of the state which is popularly known as Kalyana Karnataka region. Though it has multiuse, farmers are reluctant in adopting forestry system because of lack of knowledge on

scientific cultivation, its advantages and fear of wastage of arable land. Therefore, the survey has been carried out in the present investigation to collect reliable information about perception of farmers towards adoption of *Melia dubia* and its performance on their field. Among constraints, the field survey and the available research literature emphasize that low/poor germination of seeds of *Melia dubia* is of major one. Studies carried out so far indicated that the germination under nursery condition ranges from 14 to 28 per cent (Camus, 2008). Apart from this, farmers are in ambiguity about optimum plant density to be adopted to get higher timber yield and income. There is a need to take up studies on these research gaps for economic growth of *Melia* species under given agro-eco-system.

Whether annual crop species can be grown economically under woody perennials itself is by and large an unsettled question. While it is commonly thought, no herbaceous annual crop can successfully thrive and produce normal yield under trees, because of the so-called root and shade effects. Not much research work has been done on the combination of the trees and annual crops especially in Kalyana Karnataka area. The reason for this paucity of information appears to be the dominance of entrenched notion that trees and annual crops are mutually incompatible. The practical and convincing research information to the farmers about benefits of agroforestry systems needs to be generated.

The transformation of agriculture to more productive systems has often been accompanied by increased production in a fewer crop species. Concurrently, the area and production of a great diversity of traditional crops have declined. Yet in many parts of the world, traditional crops play an important role in maintaining stable and sustainable forms of agriculture. Among the crops, minor millets which are cultivated on low fertile lands are completely neglected.

Millets are important cereals which play a significant role in the food and nutritional security of developing countries in the semi arid tropics of Asia and Africa especially country like India. Now a day's thrust to grow millets is given due to their nutritional superiority as compared to the major cereals. In India, millets occupy an area of 818.5 thousand ha, yielding out 729.6 thousand tonnes with an average productivity of 817 kg ha⁻¹, whereas, in Karnataka, production of 12.3 thousand tonnes is realized from an area of 26 thousand ha with an average productivity of 510 kg ha⁻¹ (Anon., 2018 b). Millets are comparable to that of super cereals like rice and wheat due to their capacity to

withstand drought, adaptable to poor environment and input management. They are suitable for inclusion in multiple/intercropping systems because of its short duration and adjustable to mid season correction. Thus, millets deserve a greater importance than the major cereal crops. Being eco-friendly, these crops are suitable for fragile and vulnerable eco-systems and regarded as preferred crop for sustainable and green agriculture. Hence promotion of millets can lead to efficient management of natural resources and holistic approach in sustaining precious agro-biodiversity.

Among the eight millets, foxtail millet (*Setaria italica*) is extensively cultivated in Kalyana Karnataka region and it is an indigenous crop known for its rich nutritive value and fairly drought tolerant. In Karnataka, it occupies an area of 20.04 thousand ha, yielding out 10.99 thousand tonnes with an average productivity of 573 kg ha⁻¹ (Anon., 2018 b). Due to its quick growth, it can be grown as short term catch crop either as sole crop or inter crop with least management practices *viz.*, without applying the nutrient fertilizers or with less quantity of organic manures alone. The yield of this crop is not stable under rainfed conditions due to its cultivation on marginal or low fertile soils with less inputs use. The potential yields are yet to be achieved. The crop responds very well to organics due to its low nutrient requirements as it is mainly grown in low fertile soils and can be maintained on sustainable manner under organic system.

In this context, either under sole cropping or with agroforestry system, it is worth to mention that nutrient management through organics plays a major role in exploiting the potential crop yields apart from maintaining soil health as a results of buildup of soil organic matter, beneficial microbes and enzymes thus improving soil physical and chemical properties under organic production system. In a farming system approach, the nutrient needs are met out through recycling process. The options available on the organic farm include use of various organic manures *viz.*, FYM, vermicompost, poultry manure, biofertilizers etc., along with other practices like use of fermented organics *viz.*, panchagavya and vermiwash etc. Organic manures enrich the soil by improving the residual build up of organic carbon and available NPK and has many outstanding biological properties like bacteria, actinomycetes, fungi and cellulose degrading bacteria (Werner and Cuevas, 1996). Poultry manure which is a nutrient rich organic manure contains nutrient, three times higher than the FYM on an average as a result of combined presence of urinary and fecal excretion in the manure. Liquid organic manures are the

fermented preparations obtained by active fermentation of plant or animal residues. They influence the availability of nutrients in soil which is reflected by crop uptake. Panchagavya which is popular liquid manure among organic farmers induces quick flowering, high seed setting percentage, better growth and yield components of crops besides having growth promoting activities. Vermiwash is a rich source of vitamins, hormones, enzymes, macronutrients and micronutrients and when applied to plants, F in efficient growth (Verma *et al.*, 2018). The sound nutrient management schedule comprising proper use of all the available organic manures in the system is of utmost importance. Foxtail millet sustains in poor and marginal soils and more responsive to organic fertilizers rather than inorganic fertilizers.

The focus to utilize the available resources including interspace more efficiently in tree based farming system in general and *Melia dubia* based agri-silvi system in particular with sound nutrient management practices in the region is need of the hour. Research on influence of *Melia dubia* on associated crops is very meagre.

Keeping these points in view, the investigations have been carried out under rainfed condition in relevance to study the agroforestry system with *Melia dubia* with the following objectives under organic system.

1. Survey on performance of *Melia dubia* in agroforestry system on farmer's field in Kalyana Karnataka region.
2. To know the effect of pre-sowing seed treatments on germination of *Melia dubia* species.
3. To know the performance of foxtail millet as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system.
4. To study the early growth performance of *Melia dubia* under high density planting system.
5. To study the soil fertility status and economics of foxtail millet cultivation as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system.

REVIEW OF LITERATURE

II. REVIEW OF LITERATURE

For establishing large scale plantation of any plant species, the information regarding its standardized pre-sowing techniques, optimum plant density and its response to nutrient management practices in terms of seedling growth and establishment is very essential. In this chapter, literature pertaining to the objectives considered for the study under organic condition *viz.*, effect of pre-sowing treatments on seed germination of tree species, effect of different organic nutrient management practices on growth and yield of crops, soil fertility and economics under agroforestry system and performance of tree species under high density planting system are presented. Since, the research information related to the *Melia dubia* species pertaining to objectives of study is scanty and other related information on crops and tree species is reviewed here under.

2.1 Effect of seed treatments on germination and seedling growth of tree species

Seeds of many tree species fail to germinate even under most favourable conditions due to dormancy. Seed dormancy is regarded as the failure of an intact viable seed to complete germination under favorable conditions. The seeds of some species are prevented from completing germination because the embryo is constrained by its surrounding structures. This phenomenon is known as seed coat enhanced dormancy or physical dormancy and embryos isolated from these seeds are not dormant.

Pre-sowing treatments of seeds aim at breaking the physical barrier to enhance water absorption and expansion of the embryo. In other species, a second category of dormancy is found in which the embryos themselves are immature, which require growth and differentiation termed as morphological dormancy. A third type is called as physiological dormancy wherein the seed germination is prevented until a chemical change takes place within a seed (Nikoleava, 1977, Bewley, 1997 and Fenner and Thompson, 2005). Various kinds of pre-sowing seed treatments are being followed to break such dormancy in seeds of forest crops.

Pre-sowing seed treatments such as soaking with water, mineral solutions and organic solutions alone or in combination found to speed up germination process, increased germination rate, seedling vigour, improved resistance to water and salinity stress and increased productivity (Rahayu Wulandini and Nurin Widayani, 2007 and

Ali *et al.*, 2010). Being a low cost, easy to understand and simple technology, location specific and crop specific recommendations are needed.

2.1.1 Effect of water treatment

Many evidences are available in literature wherein germination of tropical hard coated seeds has enhanced by immersion in cold and hot water (Gupta and Thapliyal, 1974, Hartmann and Kestu, 1978). Kumar and Gopal (1975) reported that soaking of *Pterocarpus santalinus* pods in cold water for three days enhanced the germination capacity. In another experiment conducted by Naidu and Mastan (2001) on pre-sowing treatments for *Pterocarpus santalinus*, results revealed that pods treated with normal water for four days with changing water daily, soaking pods in boiled water (80 °C) till the water cools down and pods kept for alternate wetting and drying for four days showed 46, 35 and 40 per cent germination, respectively as compared to control (17%).

A study conducted by Hossain *et al.* (2005) on effect of seed treatments on germination and seedling growth attributes of *Terminalia chebula* showed the highest germination percentage of 66.7 in the de-pulped seeds soaked in cold water for 48 hours followed by 60 per cent in the de-pulped seeds soaked in cold water for 24 hours.

Sankhyan *et al.* (2005) reported that seeds of *Hippophae salicifolia* treated with hot water at 80 °C for 10 minutes resulted in maximum germination (76.7 %), shoot length (45.6 cm), root length (70.9 cm) and seedling vigour index (8931). Whereas, in case of *Hippophae rhamnoides*, seeds treated with cold water for six days resulted in maximum germination per cent (93.33), shoot length (37.8 cm), root length (53.3 cm) and seedling vigour index (8502) compared to control.

Neeraj Khera and Saxena (2008) reported that alternate wetting and drying brought significantly higher germination in teak seeds, but increasing the number of wetting and drying cycles above three days resulted in sharp decline in germination (29%).

A study conducted by Sanjay Sharma *et al.* (2008) on effect of hot water (100 °C) treatment on tropical tree species viz. *Albizia lebbek*, *Albizia procera*, *Peltophorum pterocarpum*, *Acacia auriculiformis* and *Leucaena leucocephala* showed that the germination of *Albizia lebbek* (94 %) and *Peltophorum pterocarpum* (97 %) was

maximum when seeds treated in hot water for one minute. Whereas, the germination percentage was maximum in *L. leucocephala* when treated for 5 minutes (100 %). In case of *A. procera* and *A. auriculiformis*, the germination percentage was maximum when treated for 10 minutes (94 % and 98 %, respectively).

Ramkrishna Hegde *et al.* (2009) reported that hot water treatment (seeds dipped in hot water of 80°C for 10 minutes) increased the germination (92.3%) in *Mimusops elengi*. Srinidhi *et al.* (2011) reported that alternate dipping in hot and cold water for 5 minutes each repeated thrice increased the germination percentage significantly in *Acacia holosericea* (69.3 %). The seedling vigour (5263) and germination value (3.81) were also higher in this treatment. In another study, Murugesu (2011) observed significant difference among seed treatments wherein cold water treatment for 48 hours recorded highest seed germination in *Grevillea robusta* (33 %).

Sujatha (2014) reported that pre-sowing seed treatment with cold water recorded significantly higher mean daily germination and peak value of *Melia dubia* seeds as compared to other treatments.

Bello and Gada (2015) observed 68 per cent higher germination of tamarind seeds treated with water compared to control.

Lavania (2016) reported that significantly higher germination per cent and germination value of *Picea smithiana* and *Pinus wallichiana* when seeds were soaked in water for 30 hours as compared to control.

Rai *et al.* (2018) reported significantly higher germination per cent and seedling vigour index of Khirni (*Manilkara hexandra*) seedlings in presowing seed treatment with distilled water as compared to control.

2.1.2 Effect of nutrient solution

Roy (1992) observed higher *Albizia lebbek* seed germination of 70 % compared to control (58%) by treating seed with 0.3 % KNO₃.

Preliminary studies on germination of teak seeds (*Tectona grandis* L.) were carried out at the Institute of Plant Sciences, University of Sindh by subjecting the seeds with some physical and chemical methods. Scarification treatment with GA₃, Kinetin,

H₂SO₄ and KNO₃ promoted the seed germination due to increased softening of the seed coat (Jatt *et al.*, 2007).

Sinhababu *et al.* (2007) reported that pre-treatment with nitrogenous substances like KNO₃ and thiourea were effective in increasing germination percentage of *Acacia holosericea* and *Cassia fistula*. Further, the number of days taken to reach 100 per cent germination in these species were also reduced in KNO₃ treatment.

Manasi (2011) reported that soaking the seeds of *Hydnocarus pentandra* in 0.2 per cent KNO₃ solution found to be increased germination per cent (54), mean daily germination (0.70), peak value (1.74), germination value (1.46) and germination rate (0.90) significantly when compared to cold water treatment (34 %, 0.52, 0.83, 0.43 and 0.39, respectively) and control (31 %, 0.47, 0.72, 0.34, 0.34, respectively).

Dinesh Giri and Sushma Tamta (2012) reported that seeds of *Hedychium spicatum* treated with KNO₃ (50 µM) recorded maximum germination per cent (49.9) as compared to other treatments.

A trial was conducted at College of Forestry, Sirsi during 2012-13 to standardize the nursery techniques in *Melia azedarach*. Out of nine pre-sowing seed treatments tried, the maximum germination percentage (84.0) was recorded in 200 Molar KNO₃ solution. The other quality indices *viz.*, mean daily germination, peak value, germination value and germination rate of seeding were also maximum in this treatment (Sujatha, 2014).

Rai *et al.* (2018) studied the effect of different pre-sowing seed treatments in *Manilkara hexandra* seeds at GBPAU, Pantanagar, Uttarakhand and results revealed that seeds soaking in GA₃ followed by KNO₃ solution recorded higher germination percentage, shoot length, number of leaves, shoot fresh and dry weight, root length, stem diameter, root dry weight, vigour index and root: shoot ratio as compared to control treatment.

2.1.3 Effect of cowdung slurry

Rai *et al.* (1986) reported the beneficial effects of cowdung slurry treatment on germination of *Terminalia tomentosa* and *Pterocarpus santalinus*. Cowdung attracts termites, which in turn feed on fibrous seed coat resulting in increased germination.

Similarly, Maithani *et al.* (1991) obtained higher germination percentage by treating seeds of *Desmodium tilaefolium* in cowdung slurry for three days compared to control.

According to Sankaranarayanan *et al.* (1994), seed germination in *Tamarindus indica* can be accelerated by soaking in 10 per cent cow urine or cowdung solution (500 g in 10 litres) for 24 hours. Germination was seen to increase from 37 per cent for untreated seed to 73 per cent with cow urine. Similarly, Prasanna *et al.* (1999) observed 70 per cent of seed germination in seeds of red sanders when seeds were soaked in cowdung slurry for 24 hours followed by concentrated H₂SO₄ treatment for 10 minutes. Saini *et al.* (1999) revealed that teak (*Tectona grandis*) seeds treated with cowdung slurry for 48 hours showed maximum germination percentage (31.25) and germination value (0.25).

Morpeth and Hall (2000) observed that germination of *Rosa corymbifera* Laxa was increased to 95% after pre-treatment of seeds with organic compost extract due to 20 fold increase of microbial activity in the pre-treatment mixture which resulted in higher and more predictable germination percentages. In an another experiment, seeds of *Pterocarpus santalinus* treated with cowdung slurry for 6 days showed 74 per cent germination whereas, the maximum germination of 81 per cent was obtained in seeds placed under the running tap water for 6 days. While control showed only 17 per cent germination (Naidu and Mastan, 2001). In *Elaeocarpus munronii*, where cowdung treatment recorded maximum germination percentage compared to control (Basavaraj *et al.*, 2002).

Manjunath Gouda (2005) reported that the germination of *Garcinia indica* seeds treated with cowdung slurry for 3 days was 61.3 per cent, whereas, the germination in control was 51.3 per cent. Lokesh (2007) reported that seeds of *Terminalia chebula* treated with cowdung treatment for 30 days recorded maximum germination (63.3 %) compared to control (16.7 %).

A study conducted on plantation technology for selected indigenous trees in the Indian peninsula by Nair *et al.* (2005) reported that in *Melia dubia*, percentage of seed germination was observed to be very low (14 %). Among the various pre-treatments tried, seeds soaked in farmyard manure showed the maximum germination. Krishna *et al.* (2011) reported that the seed germination of *Melia dubia* was maximum in cowdung treatment for 5 days (44.7 %) followed by mini sachet method (33.3 %). Further, seedling

quality parameters viz. seedling length and vigour index were also higher in cowdung treatment. In another study conducted by Anand *et al.* (2012) to explore the effects of different seed treatments on germination and seedling growth parameters of a multipurpose plant, *Melia dubia* in the College of Forestry, Ponnampet nursery during 2010-2011, seeds were subjected to seven pre-sowing treatments. The results showed that cowdung slurry treatment for seven days had significantly enhanced germination and seedling growth. Seed germination started 32 days after sowing and continued up to 66 days. The highest germination percentage was observed in the soaking of seeds in cowdung slurry for seven days (34.3 %) followed by 100 ppm gibberlic acid for 24 hours (31.5 %). The lowest germination percentage was obtained from control (18.7 %). The highest germination value (2.2) and germination energy (25) was also obtained in this treatment, which was significantly different from the control and other treatments. Shoot length, root length, collar diameter and leaf number followed the same trend of higher value. Similar trend was also observed in shoot, root and total seedling dry weight. Therefore, pre-sowing treatment with cowdung for 7 days was more effective in germination and production of quality seedling of *Melia dubia* in the nursery.

Manasi (2011) studied on germination of *Hydnocarus pentandra* seeds with various pre-treatments. The higher germination was observed in alternate wetting and drying in cowdung slurry for fifteen days (72.7 %). Chaya and Channabasappa (2015) reported that seeds soaking in GA₃ followed by alternate wetting and drying in cowdung slurry recorded significantly higher germination percentage, mean daily germination, peak value, germination value, germination rate of *Lagerstroemia lanceolata* as compared to all other treatments.

Sutheesh *et al.* (2016) conducted experiment at KFRI, Thrissur reported that *Santalum album* seeds soaked in GA₃ followed by cowdung slurry recorded significantly higher germination per cent, germination energy, energy period, shoot length, root length, collar diameter, leaf numbers, biomass and seedling vigour index as compared to control.

Mane *et al.* (2018) reported that custard apple seeds were soaked in thiourea (1.0 %) solution for 12 hours followed by soaking of seeds cowdung slurry for 24 hours resulted in maximum germination percentage however, minimum days required for germination, more number of leaves, maximum stem diameter, height, leaf area, fresh weight of seedling, dry weight of seedling, length of root, primary roots, secondary roots,

fresh weight of root, dry weight of root and maximum final survival percentage as compared to control.

Thanuja *et al.* (2018) reported that pre-sowing treatments with H₂SO₄ (2 %) and cowdung slurry (1:1) showed significantly improved in germination and seedling vigour of *Pterocarpus marsupium* seedlings than all other treatments.

Khushboo Tandon *et al.* (2019) conducted experiment at Gwalior, observed that pre-sowing seed treatment with GA₃ followed by cowdung slurry recorded higher germination percentage and survival of tamarind seedlings as compared to the control.

Agera Stephen *et al.* (2019) investigated the effects of cowdung and poultry droppings on the germination and early growth of *Eucalyptus camaldulensis* L. seedlings at the Forestry Nursery in Jos, Nigeria. Treatments with poultry droppings gave the greatest plant height, number of leaves and stem diameter (girth) followed by the mixture of poultry droppings and cowdung. Control recorded the lowest growth. Mixture of poultry droppings and cowdung produced the greatest leaf length, compared to poultry droppings, cowdung and control, respectively.

Pre-sowing seed treatment using water, mineral or organic solutions reduced germination period, increased germination percentage and seedling vigour, a low cost, easy to understand and simple technology for enhancing the seedling growth, location and crop specific recommendations are needed to develop in view of growing problems in stand establishment under different conditions.

2.2 Effect of agroforestry species

The rainfed ecosystems are ecologically more fragile, characterized with inadequate and ill distributed rainfall, scarcity of moisture, low organic carbon, fluctuation of water table, higher temperature and consequent higher evaporation and highly susceptible soils to erosion process. Therefore, the productivity of agriculture has declined and crop production has become more vulnerable due to climate change in spite of breakthroughs in crop varieties and crop husbandry. These days, tree based land use system is projected as a panacea for all problems in rainfed ecosystem. In fact, tree based land use system is an age old traditional practice followed by millions of farmers wherein farmers retain the useful trees on the farmland mainly to get fodder for animals, fuel

wood, timber, fruits and other minor forest products singly or together. That apart, trees are also extending many ecosystem services, such as shade, protection and demarcation of land boundaries and congenial living habitat (Chittapur and Patil, 2017).

Agroforestry is a collective term for all land use systems and technologies where woody perennials (trees, shrubs, palms, bamboos *etc.*) are deliberately used on the same land management unit as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence. In agroforestry systems, there are both ecological and economical interactions between the components. Agroforestry system includes both traditional and modern land use system, where trees are managed together with crops, vegetables, fruit trees and/or livestock production on both irrigated and rainfed conditions where it produces multiple products and ecosystem services like soil and water conservation in the short run and carbon sequestration in the long run, decrease in deforestation, creation of microclimate and conservation of biodiversity (Lundgren, 1982).

Broadly, there are three categories of agroforestry systems found on farm; first one is the age old traditional agroforestry systems, second one consisting of modules developed through the formal scientific research and the third one is borne out of research but later modified further, evolved and adopted by the farmer himself (Nair, 1996). The second and third categories of agroforestry systems are oriented towards integration of only a few tree species which are of economical importance, fast growing, input responsive and high yielding. The traditional agroforestry land use systems, however, are complex in structure and function with both complementary and competitive effects (Muturi *et al.*, 2005). However, these need to be ascertained whether the traditional agroforestry systems are ecologically more desirable, economically viable and socially preferred. Often these land use systems have significant species diversity and density variation of useful plants which are managed through planting or selection and management of naturally regenerated plants on the farm land by farmers (Schroth *et al.*, 2014).

There are many tree species are found to be suitable for agro-forestry system but recently *Melia dubia* gaining more importance and most preferred. *Melia dubia* belongs to Meliaceae family, is a promising tree highly suitable for farm forestry and agroforestry for generating higher income in the semi-arid regions. Planting of *Melia dubia* fetches

handsome price in the market, assured buyback with low maintenance expenditure. This also aid the planet by preventing temperature rise and checking gas emission into the atmosphere as the trees are naturally endowed to absorb maximum carbon dioxide. It is good for land rehabilitation and afforestation planting purposes. Its cultivation provides the economic upliftment of farmers (Kannan *et al.*, 2013). Hence the cultivation and utilization of trees is an economically viable, ecologically empathetic, environmentally ameliorative and aesthetically acceptable.

2.2.1 Performance of tree species in agroforestry system

In agroforestry, the potentially higher productivity could be due to the capture of more growth resources *e.g.*, light or water or due to improved soil fertility. Several studies in different parts of the country suggested that agroforestry is more profitable to farmers than agriculture or forestry for a particular area of land (Samra and Charan, 2000).

Evans and Rombold (1985) reported that *Melia* species can be used effectively as a tree component in agroforestry systems. The fast growth habit, deep root system, addition of large quantities of organic matter through leaf and litter fall, compatibility with agricultural crops and production of poles and firewood make *Melia* species an excellent species for agroforestry combination.

Nuthan *et al.* (2009) conducted survey in Kanakapur district, Southern Karnataka state and opioned that *Melia dubia* being a fast growing tree gives early returns and also serves as insurance to the farmers during crop failure. The wood is easily available to both farmers and wood industries at cheaper rates. Being a fast growing tree, it can be cultivated in all types of soil and requiring a low supply of water. *Melia dubia* has the unique feature of growing to 40 feet within 2 years from planting and can be mechanically pruned and harvested. It is used in plywood and match industries. Warriar *et al.* (2012) evaluated four tree species at Institute of Forest Genetics and Plant Breeding, Coimbatore and among them, *Melia dubia* recorded highest GBH (75 cm) compared to all species and growth rate was also fastest in this species as compared to *Gmelina arborea*, *Anthocephalus cadomba* and *Ailanthus triphysa*. Anusha (2012) evaluated eight tree species, among them *Melia dubia* was found to be superior in terms of height (3.20 m), DBH (23 cm), GBH (71.97 cm), collar diameter (90.87 cm) and canopy spread (7.55 and 7.91 m in north and south directions, respectively) as compared to other trees. Carbon

sequestered in *Melia dubia* was significantly higher (21.43 t ha⁻¹) as compared to other trees under agroforestry system.

Melia dubia is a promising tree and highly suitable for farm forestry and agroforestry for generating higher income in the semi-arid regions (Kannan *et al.*, 2013). Anbu *et al.* (2014) evaluated eight fast growing trees species such as *Acrocarpus fraxinifolius*, *Casuariana hybrid*, *Chukrasia tabularis*, *Eucalyptus clone*, *Melia dubia*, *Populus deltoides*, *Leucaena leucocephala* and *Thespesia populnea* at Forest College and Research Institute, Mettupalayam, Tamil Nadu. In *Melia dubia*, *L. lucocephala* and *A. fraxinifolius* the growth showed good yield such as height, basal diameter and volume index in the short period, *T. populnea* and *C. tabularis* showed the poor performance among the eight trees, but the growth performance was fair in the short period.

Scott *et al.* (2008) reported *Pongamia pinnata* as a fast growing leguminous tree with potential for high oil seed production up to 30 to 40 per cent and with the added benefit of ability to grow on marginal land. *Pongamia pinnata* has been identified as a resource for agroforestry, urban landscaping and bio amelioration of degraded lands. Devranavadgi *et al.* (2010 a) conducted study to evaluate promising tree borne oil seeds for dryland areas of Karnataka. This study revealed that *Pongamia pinnata*, *Simarouba glauca*, *Azadirachta indica* and *Melia azedirach* were suitable for dry land areas of Karnataka for oil seed purpose and for agroforestry practice, because of their fast growing nature.

Simarouba glauca is a ecofriendly and well suited tree for wasteland reclamation. Seeds contain 60 to 70 per cent oil. *Madhuca latifolia* (*Mahua*) can grow well in saline and alkaline soils with high pH value. It can be grown in soils with very low organic content. The oil content of the seed varies from 33 to 43 per cent of weight of the kernel. Both tree species can be grown in agroforestry system (Dhyani *et al.*, 2015).

Devranavadgi *et al.* (2010 b) opined that neem (*Azadirachta indica*) and Babul (*Acacia nilotica*) were the most frequently occurred tree species in northern districts under agroforestry system. Kumar *et al.* (2011) confirmed that neem (*Azadirachta indica*) can be effectively used as a tree component in agroforestry system.

Bijalwan *et al.* (2017) opioned that neem trees offer numerous profits to the farmers and it can be combined easily with many agricultural crops which wholly gives

maximum economic gains when compared to other tree species like *Leucaena leucocephala*, *Albizia lebbek* and *Acacia species*.

2.2.2 Effect of tree species on performance of associated intercrops in agroforestry system

Rao *et al.* (2000) observed higher dry matter, crop growth rate, leaf area and leaf area index in groundnut under alley cropping with *Albizia* than in sole cropping. Newaj *et al.* (2012) studied the tree crop interaction in *Albezia procera* with blackgram and mustard based agroforestry system. Germination, plant height and grain yields of blackgram and mustard were improved with increase in distance from the tree.

Mutanal *et al.* (2001) opined that grain and straw yield of sorghum were highest with sole sorghum as compared to sorghum with teak, teak + grass and teak + subabul. Grain and straw yield of sorghum were reduced significantly nearer to the teak alley compared to 5 m from the teak alley. Madeshwaran (2002) reported that the number of leaves and plant height of medicinal plants were reduced under teak based agroforestry system. Venkatarao (2005) reported that the influence of teak on the performance of groundnut was severe nearer to tree species compared to away from the tree species. Mutanal *et al.* (2009) reported that yield of finger millet was low when grown in sequence in a long term experiment on agroforestry involving arable crops (sorghum, groundnut, chilli and finger millet), horticultural crop (papaya) and pasture crops (subabul and guinea grass). Teak was planted at 10 m and 20 m apart with 2 m between plants. Finger millet yield reduction was higher *i.e.* 63.11 to 65.11 per cent in 10 m and 57.98 to 70.29 per cent in 20 m spaced teak rows compared to other crops. This was due to fast growth of teak posing severe competition with arable crops for moisture, nutrients and light. They further opined that severe yield reduction was also due to low rainfall received during the year of experimentation irrespective of the crops.

Kaushik *et al.* (2002) reported that the grain yield of pearl millet was significantly reduced in association with *Dalbergia sissoo*, *Morus alba* and *Azadirachta indica* as compared to sole crop. Ravi Kiran *et al.* (2002) studied the effect of modified microclimatic conditions on wheat inter cropped with *Eucalyptus tereticornis* and *Dalbergia sisoo*. Maximum grain yield found under control plot compared to *Dalbergia siosoo*, while, *Eucalyptus* recorded significantly lowest yield in agroforestry intercropped

system. The grain yield reduction percentage under *Dalbergia sissio* was varied from 71.58 to 80.57 per cent. In another study, Kumar and Nandal (2004) conducted field experiment on *Eucalyptus tereticornis* based agrisilviculture system wherein five test crops viz., wheat, berseem, potato, and mustard and lentil were sown as intercrops. All the tested crops sown in the interspaces of *Eucalyptus* showed reduced plant vigour in terms of plant height, stem diameter, number of branches and yield attributes as compared to control.

Swamy *et al.* (2003) observed 20 to 35 per cent of less photosynthetically active radiation (PAR) under high stands ($2 \times 2 \text{ m}^2$ tree density) of *Gmelina arborea*, which was responsible for 28 per cent reduction in soybean yield. Dai *et al.* (2008) studied the effect of *Populus deltoids* on yield of intercropped maize and wheat. Their study revealed that there was no significant difference for wheat in biomass and grain yield between intercropping and sole cropping, where as maize biomass and grain yield decreased by 37 and 31 per cent, 28 and 34 per cent for the fertilized and unfertilized treatments, respectively. Peng *et al.* (2009) found that yield of soybean and maize cultivated in walnut and plum trees were lower than their sole crop yield. This was because of competition of trees with crops. The effect of tree competition significantly reduced the PAR, net assimilation and growth. Maize crop was more severely affected than soybean. Kaur *et al.* (2009) evaluated poplar intercropped with wheat agroforestry system and they recorded significantly higher yield in sole wheat (4.39 t ha^{-1}) as compared to intercropped wheat (3.7 t ha^{-1}). Further, they also observed substantial reduction in yield of wheat intercropped with poplar trees ($4.0, 3.8$ and 3.3 t ha^{-1} during 2, 3 and 4 year of poplar, respectively). Similarly, Ding and Su (2010) investigated the effect of 10 year old and 13 m high poplars (*Populus deltoides*) on the yield of maize (*Zea mays* L.) cultivated in 50 m wide alleys in northwestern China. The maize yield in shaded areas was 22-27 per cent lower than that in non-shaded areas. Sharma *et al.* (2012) observed dry matter accumulation and nutrient uptake by wheat (*Triticum aestivum* L.) under four year old poplar (*Populus deltoides*) based agroforestry system and they reported that dry matter accumulation of wheat was lower under poplar tree line as compared to pure crop. The study on poplar based agroforestry system revealed significantly lower plant height, dry matter accumulation of plant and root length of wheat under poplar based agroforestry system as compared to the sole crop (Neema *et al.*, 2018).

Banerjee *et al.* (2009) reported that productivity of intercrops grown under *Azadirachta indica* was slightly higher compared to other trees like *Eucalyptus tereticornis*, *Acacia plectocarpa* and *Shorea robusta*. The higher productivity was due to better interception of light through the canopy in case of *Azadirachta indica* compared to other trees. In another experiment, the investigation on assessment of the productivity of understory crop blackgram in an 8 years old neem plantation indicated reduction of yield of blackgram by 58, 61 and 84 per cent as compared to sole blackgram crop in 1997, 1998 and 1999, respectively (Pandey *et al.*, 2010). In another study, Pandey *et al.* (2011) investigated the performance of chickpea (*Cicer arietinum*) under neem (*Azadirachta indica*) based agroforestry system and found that there was 29 to 40 per cent reduction in chickpea yield in two years. The availability of photosynthetically active radiation (PAR) was highly correlated with vegetative and yield attributes of the crop. Photosynthetically active radiation decreased with increase in the age of trees. Doddabasava *et al.* (2017) carried out on-farm evaluation of pigeonpea (*Cajanus cajana* L. Millsp.) - neem (*Azadirachta indica* A. Juss.) agroforestry system in the North-Eastern Dry Zone (Zone II) of Karnataka under rainfed condition and observed that significantly higher grain yield of pigeonpea (1520 kg ha⁻¹) was observed in control without any proximity to trees compared to the agroforestry systems which accounted for a mean reduction of 11 per cent in yield. Patil *et al.* (2012) conducted a field trial on *Melia azedarach* based agroforestry system. Soybean (JS-335) crop was grown in the interspace of *Melia azedarach* rows during *Kharif* every year. At the end of 10th year, the soybean yield was significantly decreased in *Melia azedarach* as compared with sole crop without tree component.

Anusha (2012) studied to know the performance of finger millet under biofuel based agroforestry trees. The grain and straw yield of finger millet was 1607 and 2936 kg ha⁻¹ with significantly higher B:C ratio of 3.60 and 3.96, respectively in *Melia dubia* agroforestry system as compared to the other trees. Divya (2013) assessed the growth and yield of different millet crops like *viz.*, foxtail millet, little millet, kodo millet, proso millet, barnyard millet and finger millet under *Melia dubia* based agroforestry system. The result showed with less light availability and soil fertility status recorded in different millet intercropping system. The finger millet recorded least growth and yield parameters as compared to other millets but foxtail millet and kodo millet noticed significantly higher grain and straw yield. Ashalatha *et al.* (2015) conducted experiments to develop suitable

Melia dubia based agroforestry models for higher productivity in Tamil Nadu. Greengram, blackgram, cowpea, bhendi, small onion, groundnut, sesame, brinjal and chillies were intercropped in 10 months old *Melia dubia*. Results revealed that the growth and yield of annual crops were found to be reduced under intercrop compared to pure crop, while the volume of trees improved when planted along with intercrops. Among the crops, blackgram (760 kg ha⁻¹) was the most affected and brinjal (8700 kg ha⁻¹) was the least affected. Growth of *Melia dubia* was also found to be influenced due to intercropping; the lowest in sesame (11.56 m³ ha⁻¹) and the highest in blackgram (19.63 m³ ha⁻¹). However, the benefit: cost ratio was the highest for brinjal (4.30:1) and the lowest for small onion (2.10:1) due to the higher productivity in brinjal. In another experiment, Pradeep (2015) observed significant reduction in growth, yield parameters and yield of finger millet under *Melia dubia* based agroforestry system when compared with sole finger millet without tree association.

Kulkarni (2017) in his participatory research on farmer's field observed that *Melia dubia* positively influenced the yield of horticulture crops rather than that of field crops. *Melia dubia* showed positive effect on quality of pomegranate fruits by reducing scorching by sunlight which saved farmers up to Rs. one lakh ha⁻¹. In general, farmers protect their pomegranate fruits from sunlight by spreading clothes, which cost around Rs. one lakh ha⁻¹. Incidence of bacterial blight was not noticed in new plantations but anthracnose (2 to 7 %) was noticed in few gardens. Papaya crop did not influence by *Melia dubia* but due to shade effect sweet lime crop was affected which reduced the yield by 8.4 per cent. At Gujarat, Bhusara *et al.* (2018) investigated the performance of greengram varieties under two year old *Melia composita* plantation at Navsari Agricultural University, Navsari and observed that growth (Plant height, number of branches and number of leaves plants⁻¹) and yield parameters (Number of flower plant⁻¹, number of pod plant⁻¹, seed yield plant⁻¹ and yield ha⁻¹) of greengram irrespective of varieties were found maximum under sole cropping compared to under intercropping system with *Melia composita*. Similarly, significantly improved growth and yield attributes of green gram plant height (48.23 cm), number of leaves per plant (247.42), number of branches (3.62), number of flowers per plant (34.04), pods plant⁻¹ (21.34) and yield (0.81 t ha⁻¹) were recorded under open condition as compared to green gram with *Melia composita* (Manmohan and Thakur, 2018). Chandana *et al.* (2020) carried out field experiment to estimate yield of pearl millet in *Melia dubia* under agri-silviculture system.

The grain yields of pearl millet were significantly lower under *Melia dubia* plantations (852–2920 kg ha⁻¹) compared to sole crop without trees (3182 kg ha⁻¹). Maximum biomass production of 6 year old *Melia. dubia* plantation was recorded as 74.9 t ha⁻¹ and minimum was 53.9 t ha⁻¹.

Bargali *et al.* (2009) studied the effects of *Acacia nilotica* on rice crop under natural conditions and with tree management. They found that reduced rice productivity by 4.7 per cent in 9 year old trees as compared to 28.8 per cent under 28 year old trees. Fadl and Sheikh (2010) studied the effect of *Acacia senegal* on growth and yield of groundnut in agroforestry system. Combined analysis indicated that intercropping reduced groundnut yield by 26 per cent. Studies conducted by Panwar and Chakravarthy (2011) to know the performance of rice under *Acacia nilotica* based agrisilviculture system found that plant height, number of panicles and straw and grain yield increased as the distance from the tree increased.

Osman *et al.* (2011) observed 21 and 67 per cent reduction in yield of cowpea and pearl millet intercropped under *Parkia biglobosa* in an agroforestry system when compared with sole crops. Intercrops yield were less affected by growth under trees.

Ram Pandit and Krishna Chandra Paude (2013) studied the introduction of *Ficus semicordata* in a maize and finger millet cropping system and agroforestry intervention in mid-hill environment. Finger millet yield in the experimental plots decreased with tree age due to shading effects, while maize yield was not substantially affected.

Sarkar *et al.* (2014) conducted a field experiment at Agroforestry Farm of Bangladesh Agriculture University for evaluating the growth performance of radish (*Raphanus sativus*) and coriander (*Coriandrum sativum*) under six year old lohkat (*Xylia dolabriformis*) tree saplings. The result revealed that the growth and yield of radish and coriander in association with the lohkat tree decreased significantly compared to open field condition.

In alfisols under dryland condition, Ramulu (2014) studied the custard apple (*Annona squamosa* L.) based agri-horti system at Bengaluru, wherein cowpea intercropped with custard apple (*Annona squamosa* L.) recorded lower number of pods plant⁻¹ (24.7), pod length (13.2 cm), number of seeds pod⁻¹ (12.1) and 100-seed weight

(16.0 g) which finally reflected in reduction of seed yield (816 kg ha⁻¹) and haulm yield (2371 kg ha⁻¹) as compared to the sole cowpea (856 and 2541 kg ha⁻¹ of seed and haulm yield, respectively). In an agroforestry system, Soumya (2015) also carried out an assessment on the influence of different tree species on finger millet yield. Reduction in yield of finger millet in association under different trees species (20.99 q ha⁻¹) was up to an extent of 30.72 per cent when compared to sole finger millet (27.44 q ha⁻¹).

Singh and Rathod (2016) studied the effect of 23 year old khejri (*Prosopis cineraria*) and rohida (*Tecomella undulata*) trees on the grain and fodder yield of *Cymopsis tetragonoloba* crop under rainfed condition. There was reduction in grain and straw yields of crop by 28.3 and 15.56 per cent in *P. cineraria* and 43.41 and 18.59 per cent in *T. undulata*, respectively compared to sole crop.

Inder *et al.* (2017) studied the bamboo based agroforestry systems and they observed significantly lower number of capsules per plant and number of seeds per capsule of sesame under bamboo based agroforestry systems as compared to pure sesame crop.

Thus, trees being perennial in nature found to influence associated agricultural crop performance depending on the age of tree, height, the canopy properties and rooting behavior.

2.2.3 Effect of tree species on soil physico-chemical properties in agroforestry system

Trees influence the soil properties and in turn on the growth and yield of plants in agroforestry systems. Tree species return sufficient amount of nutrients through litter fall. The percentage return varies with species, site and plant age. Much attention has been given in recent years to the effect of growing tree species on soil properties. Selective absorption of nutrients by different tree species and their capacity to return to soil bring about changes in soil properties.

Balamurugan *et al.* (2000) studied the effect of *Eucalyptus citrodora* on the physical and chemical properties of soil. There was a slight increase in the pH of soil under the vegetation, whereas no appreciable change in EC was observed. Moreno and Obrador (2007) studied on the impact of evergreen oaks (*Quercus ilex L.*) on soil fertility

and crop production of intercropped oats (*Avena sativa*). Soil fertility increased near the trees, with increase in soil organic matter but there was no significant difference in soil pH.

Odunze *et al.* (2008) found that intercropping of maize with forage legumes in West African savanna showed that after the two successive intercropping, growing of legumes resulted in improvement in organic carbon content in soil. *Macrotylo mauniflorum*- maize intercropping showed 39.0 per cent increase in organic carbon content, 27.3 per cent in *Stylosanthes hamata* and maize 18.4 per cent in *Macrotyloma pruriens*.

Yadav *et al.* (2008) investigated soil properties under different tree species and they noticed decrease in soil pH and higher soil organic carbon, nitrogen and phosphorus under tree species as compared to the open condition. While, Burman *et al.* (2009) studied the influence of bund planting of trees on soil properties and they observed decrease in pH, organic carbon, available nitrogen, phosphorus and potassium under tree species. Rai *et al.* (2009) revealed that the multipurpose trees in silvipastoral system decreased soil pH as compared to control. Change in soil pH under silvipastoral system compared to control was due to combined effects of decay of multipurpose tree litter, sloughing off roots and changed microclimate.

Baljit *et al.* (2010) studied the soil properties under different tree species and the results indicated significantly higher organic carbon and available nitrogen, phosphorus and potassium under tree as compared to open condition. Nandal and Kumar (2010) reported that there was a reduction in soil pH and EC among the *Melia azedaracha* intercrops compared to initial value of 8.9 and 9.5 dSm⁻¹. At the harvest stage of intercrops, there was depletion in phosphorus and potassium compared to initial value. Patil *et al.* (2010) while assessing physico-chemical properties of soil under different forest species reported that organic carbon and availability of N, P and K were higher in soil under trees compared to control (without trees). Similarly, Singh *et al.* (2010) studied the influence of tree plantation on soil physico-chemical properties and they observed appreciable increase in the available nutrient contents in the sites under vegetation as compared to open condition.

Zouheir and Chaib (2011) reported that there was no significant difference in soil pH and EC between the wheat based intercropping under *Acacia tortilis* and tree alone treatments. Soil chemical properties were higher under canopied sub habits.

Anusha (2012) studied the soil physico-chemical properties of agroforestry systems of different tree species including *Melia dubia* with finger millet as intercrop and the study revealed higher soil pH (6.2) in sole fingermillet as compared to agroforestry systems (5.93).

Gupta *et al.* (2012) reported that the available nitrogen, phosphorus and potassium were higher under *Eucalyptus tereticornis* plantation as compared to control plot. Nitrogen content under silvipasture system was 278.4 kg ha⁻¹ compared to the control 223 kg ha⁻¹.

Avinash *et al.* (2013) studied the soil properties of mango based agro-horti-forestry system (mango + cowpea–toria system) and observed improvement in organic carbon, total nitrogen, phosphorus and potash and reduced pH (49.0, 56.3, 48.6, 58.5 and 11.6 per cent, respectively) as compared to initial values within soil depth of 0-30 cm.

Maria *et al.* (2013) evaluated the soil fertility in an agroforestry system with *Leucaena diversifolia*, maize (*Zea mays*) and black oats (*Avena strigosa*). The results revealed that pH, EC, N, P, K status in soil were higher under agroforestry system as compared to pure crops.

Umar *et al.* (2013) investigated the effects of *Faidherbia albida* on soils by testing for differences in the soil reaction (pH), total nitrogen, potassium, phosphorus and organic carbon at increasing radial distance from the tree trunk.

Pradeep (2015) reported that sole fingermillet recorded significantly lower soil available nutrients like N, P, K (406.32, 21.03 and 201.40 kg ha⁻¹, respectively) compared to intercropping with *Melia dubia* based agroforestry system (412.21, 21.14 and 205.72 kg ha⁻¹, respectively).

Bilas Singh *et al.* (2014) found that there was a decrease in soil pH after harvesting of intercrops. Reduction in soil pH was higher in the intercropping field compared to sole crop in agrisilvicultural system.

Yadav and Bisht (2014) carried out a field investigation to study litter fall production and nutrient contents in the litter fall under crown of pecan nut tree in rainfed condition. Total annual accretion of litter fall was found to be 2143.3 kg ha⁻¹ year⁻¹ and relative abundance of nutrients in litter fall of pecan nut tree were in the order C>N>K>P. The total nutrients build up from above mentioned litter fall of pecan nut was carbon (901.91 kg ha⁻¹ year⁻¹), nitrogen (57.44 kg ha⁻¹ year⁻¹), phosphorus (3.21 kg ha⁻¹ year⁻¹) and potassium (43.29 kg ha⁻¹ year⁻¹).

Bhardwaj *et al.* (2017) investigated the effect of *Eucalyptus tereticornis* bund planting on soil fertility. There was increased in soil pH and EC at initial stage of tree growth then decreased in these parameters as growth progresses.

Jones *et al.* (2017) studied the influence *Faidherbia albida* based agri-silvi system on soil properties and observed higher total nitrogen, phosphorus and potassium by 1.12 mg g⁻¹, 0.11 mg kg⁻¹ and 0.09 mg kg⁻¹ respectively in agroforestry system compared to outside the canopy and the same trend was also noticed with soil organic carbon. Similarly, in North Eastern Karnataka, India, Doddabasava *et al.* (2017 b) carried out soil analysis in different neem-based agroforestry systems under rainfed condition. They observed that physico-chemical properties of soil were found to be improved in agroforestry systems compared to control.

The analysis of soil properties of agroforestry systems indicated significantly higher organic carbon and available nutrients in agroforestry systems compared to sole agricultural systems, whereas increased soil pH was observed under sole agricultural system than under agroforestry systems (Indra *et al.*, 2018).

Muktar *et al.* (2018) studied the influence of scattered *Cordia africana* and *Croton macrostachyus* trees on soil properties. The soil pH and EC were not significantly influenced by both tree species whereas, significantly higher soil organic carbon, total nitrogen, available phosphorus, exchangeable K and CEC were recorded under the tree canopy in both the tree species and at different depths of soil as compared to the open field.

Patel *et al.* (2018) analyzed the soil properties of 30 years old different multipurpose (MPT's) agroforestry tree plantations under rainfed situation *viz.*, *Azadirachta indica*, *Prosopis cineraria*, *Prosopis juliflora* and *Acacia tortolis* and they

observed significantly lower soil pH and EC in all the plantations as compared to the open field. Whereas, substantially higher soil organic carbon, available nitrogen, available phosphorus and available potash were recorded in all the tree species compared to the open field.

2.2.3 Effect of tree species on soil biological properties (microbial population and enzyme activities) in agroforestry system

Chander *et al.* (1998) studied the soil properties in agroforestry practices and recorded improved microbial biomass and enzyme activity in agroforestry practices as compared to the sole crops. Manish and Tarafdar (2004) assessed the density and diversity arbuscular mycorrhizal fungi population in neem based agroforestry system and they observed *Glomus*, *Gigaspora* and *Sclerocystis* genera of fungi in neem-based agroforestry system and results indicated that *Glomus fasciculatum* was the dominant stable arbuscular mycorrhizal fungi (AMF) in neem-based agroforestry system.

Rajendra and Mertia (2005) studied the dehydrogenase activity and VAM fungi association in rhizosphere of six agroforestry trees (*Azadirachta indica*, *Acacia tortilis*, *Eucalyptus camaldulensis*, *Prosopis cineraria* and *Tecomella undulata*) under irrigated and rainfed conditions in the arid zone of India. Higher dehydrogenase activity (9.5 to 16.8 $\mu\text{p kat g soil}^{-1}$), root colonization (58.3 to 68.5 %) and spore density (132.5 to 234.7 spores 100 g soil⁻¹) were observed in tree rhizosphere as compared to that of non-rhizosphere (7.4 $\mu\text{p kat g soil}^{-1}$, 37.7 % and 44.4 spores 100 g soil⁻¹).

Srinivasan and Mohan (2006) studied the microbial density in different agroforestry systems and observed higher bacterial population (64%) followed by actinomycetes (23%) and fungi (13%) in different soil samples in agroforestry system as compared to the agricultural system.

Yadav *et al.* (2011) studied the microbial biomass carbon in different agroforestry systems and observed that soil microbial biomass C was higher ranging from 262-320 $\mu\text{g g}^{-1}$ under agroforestry corresponding to lower soil microbial biomass C (186 $\mu\text{g g}^{-1}$) under tree-less control. The impact of land use intensity on arbuscular mycorrhizal fungi (AMF) was also investigated at six land use types *viz.*, natural forests, grasslands, acacia, cardamom, coffee plantations and paddy fields, in the Western Ghats in Southern India. The results indicated that at post-monsoon season, the root colonization, spore density,

number of infective propagules and species diversity of AMF were significantly higher in natural forests and grasslands followed by plantations and least was noticed in paddy fields (Lakshmipathy *et al.*, 2012).

Bainard *et al.* (2013) suggested that the tree based intercropping system support a more diverse soil microbial community compared to conventional agriculture system. They also concluded that fungi from both cropping systems had a positive effect on the growth of plants that formed a functional symbiosis.

Ramulu (2014) recorded significantly higher bacteria, fungal and actinomycetes populations (44.32×10^5 cfu g⁻¹ of soil, 32.4×10^4 cfu g⁻¹ of soil and 19.66×10^3 cfu g⁻¹ of soil, respectively) in custard apple + cowpea agro-horti system, which was on par with custard apple + field bean system (42.63×10^5 cfu g⁻¹ of soil, 30.04×10^4 cfu g⁻¹ of soil and 18.70×10^3 cfu g⁻¹ of soil, respectively). Significantly lower microbial population of bacteria, fungi and actinomycetes was registered in custard apple alone (22.59×10^5 cfu g⁻¹ of soil, 16.70×10^4 cfu g⁻¹ of soil and 10.66×10^3 cfu g⁻¹ of soil, respectively).

An experiment was carried out to study the effect of spacing of tree species on native AMF and microbial biomass carbon in the soil in an alley cropping system. The treatments comprised three spacings (4, 8 and 12 m) between two tree species, *Leucaena leucocephala* and *Glyricidia sepium* and three field crops, viz., finger millet, peanut and pigeonpea, grown between trees. All the three field crops grown between *Leucaena* had higher fungi propagules compared to those grown in between *Glyricidia*. The microbial biomass carbon in soil was more in all the three alleyed crops grown in between *Glyricidia*. Spacing of 12 m between trees supported most of the microbial parameters studied and the yield of all the three field crops (Balakrishna *et al.*, 2016).

Doddabasava *et al.* (2018) studied the microbial density in *Azadirachta indica* A. Juss. based agroforestry systems in North-Eastern Tropical Karnataka, India and the study revealed that populations of bacteria, fungi and actinomycetes in neem-based agroforestry systems were the highest in boundary planting (25.75×10^6 , 18.08×10^3 and 10.91×10^2 cfu g⁻¹ soil, respectively) followed by scattered planting (19.74×10^6 , 14.41×10^3 and 9.58×10^2 cfu g⁻¹ soil, respectively) and bund planting (20.30×10^6 , 11.33×10^3 and 7.05×10^2 cfu g⁻¹ soil, respectively) and these systems were significantly higher as compared

to monoculture of pigeonpea (14.83×10^6 , $3\ 208.33 \times 10^3$ and 5.00×10^2 cfu g⁻¹ soil, respectively).

Indra *et al.* (2018) revealed that bacterial population was significantly higher (62.67×10^6 cfu g⁻¹ soil) in surface and sub-surface soil (33.33×10^6 cfu g⁻¹ soil) under *Quercus leucotrichophora* based agroforestry system as compared to control (35.00×10^6 cfu g⁻¹ soil 13.00×10^6 cfu g⁻¹ soil, respectively).

Yengwe *et al.* (2018) observed higher soil microbial diversity under tree canopy as compared to outside the tree canopy in *Faidherbia albida* intercropped with maize.

Thus, microbial population is positively correlated with the soil organic carbon and nutrients which varies with tree density. Therefore, various scientists opined soil microbial inventory is essential from the point of soil health and production sustainability in the semi arid tropics. Influence of tree species on associated agricultural crops also depends on the impact of tree species on soil biota which varies with species, age *etc.*

2.2.4 Effect of tree species on biomass and carbon sequestration in agroforestry system

Tree component in agroforestry systems is significant sink of atmospheric carbon (C) due to their fast growth and high productivity. By including trees in agricultural production systems, agroforestry can, arguably increase the amount of C stored in lands devoted to agriculture, while still allowing for the growing of food crops (Kursten, 2000). In agroforestry system, tree components are managed, often intensively by pruning of minimizing competition and maximize complementarity. The pruned materials are mostly non- timber products. Such materials are often returned to soil. Besides, the amount of biomass and therefore C that is harvested and exported from the system is relatively low in relation to the productivity of the tree. Therefore, unlike in tree plantations and other mono culture systems, agroforestry seems to have unique advantage in terms of C sequestration.

Swamy and Sunil (2005) assessed biomass production and C sequestration of 5 years old *Gmelina arborea* plantation and agroforestry system in Uttaranchal, India and observed higher biomass and carbon sequestration in *Gmelina arborea* plantation (17.5

Mg ha⁻¹) which was 35 per cent higher than *Gmelina arborea* based agrisilvi system (14.1 Mgha⁻¹).

Kaul *et al.* (2010) studied the dynamic growth model (CO₂FIX) and used for estimating the carbon sequestration potential of sal (*Shorea robusta*), *eucalyptus* (*Eucalyptus tereticornis*), poplar (*Populus deltoides* Marsh) and teak (*Tectona grandis*) forests in India. The results indicated that long-term total carbon storage ranges from 101 to 156 Mg C ha⁻¹, with the largest carbon stock in the living biomass of long rotation sal forests (82 Mg C ha⁻¹). The net annual carbon sequestration rates were achieved for fast growing short rotation poplar (8 Mg C ha⁻¹ year⁻¹) and *Eucalyptus* (6 Mg C ha⁻¹ year⁻¹) plantations followed by moderate growing teak forests (2 Mg C ha⁻¹ year⁻¹) and slow growing long rotation sal forests (1 Mg C ha⁻¹ year⁻¹). Due to fast growth rate and adaptability to a range of environments, short rotation plantations, in addition to carbon storage rapidly produce biomass for energy and contribute to reduced greenhouse gas emissions.

Kumar (2010) studied four different agroforestry systems of nine year old (*Populus deltoides* block plantation + wheat, *Eucalyptus* hybrid boundary plantation + wheat, *Populus deltoides* boundary plantation + wheat and *Populus deltoides* block plantation + lemon grass) and it was noticed that the total carbon sequestration in trees was 70.59, 21.38, 116.29 and 18.53 t C ha⁻¹ in system *Populus deltoides* + wheat followed by 68.53, 20.63, 113.03 and 17.60 t C ha⁻¹ in system *Populus deltoides* + lemon grass respectively with greater potential for carbon sequestration in boundary plantation of *Populus deltoides* and *Eucalyptus* hybrid.

Anusha (2012) studied the performance different five biofuel yielding plants at ZARS, GKVK, Bengaluru during 2011 and among them, *Melia dubia* as compared to other trees, recorded higher biomass (39.95 t ha⁻¹) resulting in higher carbon sequestration (21.43 t ha⁻¹).

Suryawanshi *et al.* (2014) in their investigation, above ground biomass and below ground biomass carbon sequestration potential of selected tree species of Northern Maharashtra University campus in Jalgaon city was measured. *Moringa olifera* species was found to be dominant sequestered 15.775 t of carbon and having 14 trees followed

by *Azadirachta indica* (12.272 t). The species *Eucalyptus citriodora* had lowest carbon sequestration potential *i.e.*, 1.814 t.

Chauhan *et al.* (2015) reported carbon sequestration potential of poplar based agroforestry systems and recorded higher carbon storage in block plantation (55.3 t ha⁻¹) followed by boundary planting (32.70 t ha⁻¹) and the least was recorded in sole cropping of wheat (30.2 t ha⁻¹).

Tanwar *et al.* (2019) evaluated the carbon sequestration potential of eight recommended land-use systems of arid western Rajasthan. Biomass C stock was maximum in farm forestry of *Acacia tortilis* (31.4 Mg C ha⁻¹) followed by *Prosopis cineraria* and *Hardwickia binata* based silvoarable systems (8.8 and 10.6 Mg C ha⁻¹). Soil C stock was also maximum in farm forestry (47.6 Mg C ha⁻¹) followed by *Ziziphus* based systems (32.5–33.9 Mg C ha⁻¹). About 50–78% of additional soil C stock was in the form of soil inorganic carbon. The total C sequestered (biomass + soil) over a period of nineteen years was in the order: farm forestry (49.80) > silvoarable systems (11.0–13.3) > hortipasture system (8.3) > agri-horti (5.5), silvopasture (5.4) and sole pasture (5.3) compared to 1.0 Mg C ha⁻¹ in sole cropping.

Chandana *et al.* (2020) conducted field experiment to estimate biomass and carbon stock of *Melia dubia* under agri-silviculture system. Maximum biomass production of 6 year old *Melia dubia* planting was 74.9 tha⁻¹ and minimum was 53.9 tha⁻¹. Contribution of *Melia dubia* to total carbon stock and carbon dioxide sequestration was observed in the range 27.0–37.5 and 98.9–137.5 t ha⁻¹ respectively.

2.2.5 Economic analysis of agroforestry systems

Singh *et al.* (1989) critically examined above and below ground interactions in alley cropping and found that growth and economic yield of crops declined from 15 to 30 per cent than that of sole crops but increased net returns in alley cropping system.

Jain and Singh (1999) reported that intercropping of poplar with agricultural crops reduced crop yield as age of the tree increased. There was substantial increase in the farm income from the poplar based agroforestry systems compared to sole crops. This was due to the increased poplar yield and income, which compensates the loss in crop income. The net returns from wheat in poplar + wheat system was Rs 5,636 ha⁻¹, Rs 4,310 ha⁻¹ and

Rs 3,858 ha⁻¹ during first, second and third year, respectively compared to average net returns from sole crop of wheat (Rs. 2731 ha⁻¹). With the advancement of age of the system the income decreased due to increased competition. The net income from wheat intercrop was lower by about 55 per cent over sole crop in the 8th year. The benefit cost ratio was 1.75 and 2.30 in poplar based wheat and sugarcane systems compared to their sole agricultural crops (1.29 and 1.80 respectively).

Chauhan (2000) observed average net return of Rs. 25690 ha⁻¹ year⁻¹ from sole plantation of *Populus deltoides* and Rs. 43590 ha⁻¹ year⁻¹ from lemon grass, Rs. 39670 ha⁻¹ year⁻¹ from palmarosa and Rs. 36370 ha⁻¹ year⁻¹ from Japanese mint using poplar based agroforestry system in a period of five years.

Dutt and Thakur (2014) calculated monetary status of cropping systems for two consecutive years under Shivalik Ranges of outer Himalayas, combining medicinal and aromatic herbs with commercial timber species. Four herbal crops namely *Ocimum sanctum*, *Spilanthes acmella*, *Tagetes minuta* and *Withania somnifera* were intercropped with 6 year old plantation of populus hybrid (G-48) having 8 x 3 m, 6 x 4 m, 5 x 5 m and 4 x 6 m spacing. Net returns were comparatively more under agroforestry systems combining *Ocimum sanctum* and *Tegetes minuta* with poplar at different spacing in comparison to monocropping.

The study conducted at Vijayapur, Karnataka revealed that agroforestry systems comprising chickpea + *Hardwickia binata* trees recorded higher net returns (Rs 10,122 ha⁻¹) and a B:C ratio of 2.69 than with species like *Acacia*, *Dalbergia*, *Cassia*, *Albizia* and *Leucaena* (Devaranavadgi *et al.*, 2005).

Mutnal *et al.* (2009) reported that grain yield of arable crops was higher in 20 m alley of teak + papaya rows as compared to 10 m alley of teak + papaya. Among the four crops, average grain yields were obtained in the order of sorghum > groundnut > ragi > chilli with teak. Net returns were in the order of groundnut > sorghum > ragi > chilli and sorghum > groundnut > ragi > chilli. Groundnut and sorghum crops realized stable yields and returns as compared to chilli or ragi. Grain yields were significantly higher in teak + papaya as compared to teak + papaya + grass.

Aarif *et al.* (2010) observed that sole cropping of sunflower was superior (636 kg ha⁻¹) to inter cropped sunflower in six year old *Hardwickia binata* after stylo (342 kg ha⁻¹)

followed by the crop grown after fallow in *Hardwickia binata* (248 kg ha⁻¹). However, the total monetary returns from tree and crop considerably were found to be higher in intercropped sunflower grown with *Hardwickia* (Rs 5,287 ha⁻¹) when compared to sole cropped sunflower (Rs 4,134 ha⁻¹).

Nandal and Kumar (2010) conducted an experiment to study the *Melia* based agroforestry, forestry and agriculture land use systems on economic feasibility. The green matter yield of dhaincha (*Sesbania aculeata*), grain yield of wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare*) and green fodder yield of berseem (*Trifolium alexandrinum*) remained unaffected due to *Melia azedarach* during the first four years of plantation. However, from fifth year onwards, yield of all the crops decreased under *Melia* compared to control (field without trees). Dhaincha-berseem crop rotation gave the highest net present value, benefit cost ratio and internal rate of return.

The economic analysis of 10 years old *Melia azedarach*-soybean based agroforestry system was carried out by Patil *et al.* (2012) at Main Agricultural Research Station, University of Agricultural Sciences, Dharwad, India and they recorded higher gross return in *Melia azadirach*-soybean based agroforestry system (Rs 10,502 ha⁻¹ year⁻¹) and B: C of 1.86 as compared to sole soybean (Rs 6,410 ha⁻¹ year⁻¹ with B: C ratio of 1.73).

Wekesa *et al.* (2012) conducted a study on economic viability of *Melia composita* using net present value (NPV) and annual equivalent value (AEV) on data collected from 92 small holder farmers and 20 processors/traders in four dry lands districts of Kenya. Results showed that one hectare (ha) under *Melia* required an investment of US\$ 15,586 for a 10 year rotation cycle, covering tree establishment to timber production. The highest profitability was achieved when intercropped with greengram at initial stages of establishment accompanied with value adding into timber. In this situation, one ha of *Melia* stand gave NPV of US\$ 15,128 translating to a discounted annual profit margin of US\$ 2,055 for 10 years. Comparatively, profitability of *Melia* was higher than *Eucalyptus camaldulensis* and *Grevillea robusta* in a similar environment.

Anusha (2012) studied the performance of finger millet under different biofuel yielding plants based agroforestry system, among them finger millet with *Melia dubia* recorded higher net returns and B:C ratio than finger millet with other tree species.

Vishwanath (2013) analyzed the economics of different agroforestry systems (AFS). The mean of various agroforestry system revealed lower net returns of Rs. 37,220 ha⁻¹ and B: C ratio of 2.19 compared to sole soybean which recorded net returns of Rs. 62,285 ha⁻¹ and B:C of 2.99. These were the highest in *Madhuca latifolia* + soybean (Rs. 52,115 ha⁻¹ and 2.66) and were the lowest in *Azadirachta indica* + soybean (Rs. 30,695 ha⁻¹ and 1.98).

Ashalatha *et al.* (2015) conducted experiments to develop suitable *Melia dubia* based agroforestry models for higher productivity and economics in Tamil Nadu. Greengram, blackgram, cowpea, bhendi, small onion, groundnut, sesame, brinjal and chillies were intercropped in 10 months old *Melia dubia*. Results revealed that benefit: cost ratio was the highest for brinjal (4.30:1) and the lowest for small onion (2.10:1) due to the higher productivity in brinjal.

At Jabalpur, Madhya Pradesh, India, Rahangdale *et al.* (2014) studied intercropping in three-year-old plantation of *Bambusa arundinacea* and *Dendrocalamus strictus* planted with a spacing of 5 m x 5 m during rainy season with 4 intercrops *viz.*, green gram, soyabean, paddy and sesame. The economic analysis of the system revealed that the bamboo based agroforestry system gave higher monetary returns (Rs. 21,029 ha⁻¹) as compared to sole bamboo of Rs. 9,801 ha⁻¹. Growing of green gram with bamboo species gave significantly higher net monetary returns of Rs. 27,736 ha⁻¹ but it was at par with sesame Rs. 23,365 ha⁻¹.

At AICRP, GKVK, Bengaluru, Pradeep (2015) conducted experiment on *Melia dubia* trees intercropped with finger millet, observed significantly higher net returns and B:C ratio (Rs. 141714 ha⁻¹ and 4.53, respectively) when compared with sole crop of finger millet (Rs. 48130 ha⁻¹ and 3.78, respectively).

Prakash and Pant (2015) found that intercropping of flower crop *Godetia grandiflora* with *Grewia optiva* proved an excellent agroforestry system to enhance the socio-economic status of farmer as well as country as a whole and they reported higher B: C ratio (2.66) in agroforestry system compared to pure *Grewia optiva* plantation (1.50).

At Gujarat, Thakur *et al.* (2016) conducted an experiment in the experimental farm of ASPEE, College of Horticulture and Forestry, Navsari Agricultural University, Navsari, India on economics of three *Ocimum* species, namely *Ocimum tenuiflorum*,

Ocimum gratissimum and *Ocimum basilicum*, which were grown under 18 year old teak (*Tectona grandis*) based silvi-medicinal agroforestry system (teak+ *Ocimum* spp.). The study revealed that herbage production of *Ocimum gratissimum* was the highest with net returns of Rs. 38,018 ha⁻¹ with B: C ratio 1.85. The essential oil production from *Ocimum basilicum* accrued the highest net returns of Rs. 103327 ha⁻¹ with B: C ratio of 2.56.

Chandana *et al.* (2020) carried out field experiment to study the economic performance of *Melia dubia* under agri-silviculture system. The grain yields of pearl millet were significantly lower under *M. dubia* plantations (852–2920 kg ha⁻¹) compared to sole crop without trees (3182 kg ha⁻¹). The net returns obtained from the tree were lowest (Rs. 116,134 -182,885 ha⁻¹) when compared to the tree + crop (Rs 139,953 - 209,650 ha⁻¹) system. The lowest net returns were observed in sole crop without trees (Rs. 27,351 ha⁻¹). Thus, *M. dubia* plantations contributed towards higher economic performance of agri-silviculture system as compared to sole crop.

2.2.6 Effect of organic nutrient management practices in agroforestry systems

2.2.6.1 Effect on growth and yield of field crops

The literature pertaining to performance of agroforestry system with *Melia dubia* species under organic system is scanty. The related information on use of organics with inorganic sources of nutrients in agroforestry system is presented here under.

Panneer and Bheemaiah (2005) conducted field experiment to evaluate three intercropping systems (sunflower with neem, sunflower with *Melia* and sole cropping of sunflower) under different integrated nutrient management practices and reported that all integrated nutrient management practices significantly enhanced nitrogen uptake and seed yield of sunflower in agroforestry system as compared to control.

Jat and Thakur (2010) carried out field experiment to assess the integration of medicinal herb (*Matricaria chamomilla*) with poplar trees by using organic manure as sources of soil nutrient to minimize competition for resources. The results revealed that *Matricaria chamomilla* can be grown successfully with poplar trees. The presence of trees had little suppressing effect on the yield and other growth parameters of herb even at distance close to tree trunk. The use of organic manures like vermicompost and FYM at appropriate doses was found beneficial for minimizing competition for critical resources.

Thakur *et al.* (2010) studied the compatibility of medicinal and aromatic herb species in association with poplar trees. Integration of medicinal and aromatic herbs namely, *Digitalis lanata*, *Matricaria chamomilla* and *Salvia sclaria* with *Populus deltoides*, planted at 4 x 4m spacing. It was indicated that no substantial adverse impact of the presence of tree canopies on growth, yield and physiological parameters of these medicinal and aromatic herbs. Application of fertilizers and farmyard manure was found to be very useful for enhancing growth and production ability as well as photosynthetic efficiency of all the herb species. Growth with respect to height, leaf number, spread, flower number, branch number and leaf area index, all index of better growth was significantly higher in FYM treated plots in comparison to control.

Sehgal (2011) conducted field experiment to examine the effect of organic manures on *Ocimum basilicum* intercropped with *Leucaena leucocephala*. The use of organic manures benefited the intercrop by improving the growth even in the presence of hedgerows as compared to control plots (without trees).

Umrao *et al.* (2013) conducted experiment on effect of organic manures on growth and yield of garlic (*Allium sativum*) under *Tectona grandis* based agroforestry system with seven treatments each in open and shade conditions. The treatment combinations used were control, FYM, vermicompost, neem cake, 50% FYM + 50% vermicompost, 50% FYM + 50% neem cake, 50% vermicompost + 50% neem cake. The results showed that different treatment of organic manures had a positive effect on the growth and yield of plants under both open and shaded conditions but plants grown under shade conditions performed better in comparison to the ones grown in the open. Among all the treatment combinations, application of FYM had better influence on growth and yield of garlic under open and shade conditions but more yield was obtained with the application of FYM under light shade of trees.

Kumar *et al.* (2014) conducted a study to investigate the influence of different organic manure doses on the herbage biomass and essential oil yield and oil quality of patchouli under teak based agroforestry system. They concluded that among seven treatments of different organic manure tested, the 100% vermicompost exhibited significantly higher dry herbage yield, essential oil yield and oil content (%) in first, second and third harvest per year from patchouli crop under teak based agroforestry system.

Bhat (2015) conducted experiment to know the performance of vegetables (capsicum, tomato, garden pea and cauliflower) under different sources of organic manures in *Melia composita* based agroforestry system at Nauni, Solan (UP). Result indicated that optimum use of organic manures benefited the intercrops by improving the growth of plants even in the presence of trees as compared to sole plots during both *Kharif* and *Rabi* crop season. In most of the cases vermicompost @ 5 t ha⁻¹ showed highest crop yield followed by vermicompost @ 3.5 t/ha and FYM @ 10 t ha⁻¹ when compared with control.

Khan and Krishna (2016) conducted field experiment on finger millet and foxtail millet in *Melia azedarach* (two and three years age old) based agri-silvi system during *Kharif* 2014 and 2015 at Agroforestry Research Block, PJTSAU, Hyderabad, Telangana State. The treatments consisted of alone and combinations of organic manures, biofertilizers, chemical fertilizers in agroforestry system and without tree system *i.e.* sole crop. The highest grain (2681 kg ha⁻¹) and straw yield (5063 kg ha⁻¹) of finger millet recorded in sole crop but on par with 75% RDN + 25% N through poultry manure (2405 and 4733 kg ha⁻¹) and 100% RDF (2393 and 4745 kg ha⁻¹). The lowest grain (1583 kg ha⁻¹) and straw yields (3402 kg ha⁻¹) were found with control (FYM 10 t ha⁻¹ *i.e.*, farmers practice).

Field experiment was conducted with finger millet variety (PRS-2) at Agroforestry Research Block, Acharya N.G Ranga Agricultural University Campus, Rajendranagar, Hyderabad during *Kharif*, 2013. Finger millet was grown under three year old *Melia species* in red sandy loam soil with different management options. Among nutrient management practices tested, 75% RDN + 25% N through poultry manure and 100% RDF in agri-silvi culture system was better for realizing higher grain yield, straw yield and economic returns apart from sustaining better soil nutrient status on sandy loam soils of Southern Telangana region (Pallavi *et al.*, 2016).

Chandana *et al.* (2018) conducted field experiment during *Kharif* 2017 to study the effects of nutrient management practices on yield attributes and yield of pearl millet intercropped in *Melia dubia* based agri-silvi system. Results of the experiment showed that sole crop without trees recorded significantly higher yield attributes, grain yield and stover yield followed by 100% RDF through neem coated urea. But, among organic

sources, application of 75% RDN through poultry manure + pongamia green leaf manure @ 10 t ha⁻¹ significantly influenced the yield attributes, grain yield and stover yield of pearl millet in *Melia dubia* based agri-silvi system followed by 75 % RDF + 25 % N through poultry manure.

Kar *et al.* (2019) carried out a field experiment to explore the possibilities of successful cultivation of garden pea as intercrop under different spacings of *Grewia optiva*. Growing of Garden pea with the use of 120 % of the recommended doses of nitrogen through vermicompost and poultry manure under 8 m x 3 m spacing was found better to other treatment combinations with respect to growth, yield, net revenue and B:C ratio.

2.2.6.2 Effect of organic nutrient management practices on soil properties in agroforestry system

Mucheru *et al.* (2007) conducted an experiment to investigate the effects of different soil incorporated organic manures in maize with *Tithonia diversifolia*, *Calliandra calothyrsus* and *Leucaena leucocephala* agroforestry system. After 2 years of trial implementation, total soil carbon and nitrogen contents were improved with the application of organic manure as compared to the control.

Bhat (2015) observed higher doses of organic manures like vermicompost and FYM were more effective in increasing the N, P, K, EC and soil organic carbon content of soil when compared to no organic manure in vegetables intercropped with *Melia composita* and without tree interface.

Khan and Krishna (2016) conducted field experiment to study the suitability of finger millet and foxtail millet in *Melia azedaracha* (two and three years age old) based agri-silvi system and results revealed that available NPK were increased significantly in 75 % RDN + 25 % N through poultry manure (291.8, 39.0, 355.3 kg ha⁻¹, respectively) and 100 % RDF (283.9, 38.7, 354.8 kg ha⁻¹, respectively) on par with sole crop (317.0, 37.8, 366.0 kg ha⁻¹, respectively). The nutrient contents in grain and straw with the same treatment resulted the highest NPK contents in grain (1.30, 0.36, 0.49 %, respectively) and straw (0.63, 0.13, 2.52 %, respectively) followed by 100% RDF (1.28, 0.236, 0.46 and 0.60, 0.133, 2.36 %). Similar trend was also continued in case of NPK uptake by grain and straw (25.14, 5.00 10.24 and 22.47, 4.24, 90.12 kg ha⁻¹). Pertaining to soil

properties there was no significant effect on pH and EC but there was a significant effect and the highest OC (0.59 %) and available NPK (149.7, 24.95, 219.0 kg ha⁻¹) by the integrated use of 75 % RDN + 25 % N poultry manure.

Chandana *et al.* (2018) conducted field experiment during *Kharif* 2017 to study the effects of nutrient management practices on yield of pearl millet and soil fertility status in *Melia dubia* based agri-silvi system. Results of the experiment showed that application of 75 % RDN through poultry manure + pongamia green leaf manure @ 10 t ha⁻¹ significantly influenced grain yield and stover yield of pearl millet and available NPK and nutrient uptake in *Melia dubia* based agri-silvi system followed by 75 % RDF + 25 % N through poultry manure.

Bhat (2018) conducted experiment on “Effect of integrated nutrient management and tree spacing on wheat-maize cropping system under poplar based agroforestry system” at the experimental farm of Department of Silviculture and Agroforestry, Nauni, Solan (H.P.) for two consecutive years from May, 2015 to May, 2017. Application of 50% FYM and 50 % vermicompost resulted in significant improvement in soil physico-chemical and biological properties under agroforestry system as compared to open (tree less area). Significantly higher availability of nutrients was observed in agroforestry system as compared to soil in sole crop.

Pallavi *et al.* (2019) conducted field study to know the effect of INM on soil fertility and productivity of finger millet in agroforestry system at Agroforestry Research Block, Acharya N.G Ranga Agricultural University campus, Rajendranagar, Hyderabad. Application of poultry manure and 75 % recommended dose of nitrogen showed its best results with respect to grain yield (2681 kg ha⁻¹) as compared to other treatments. The nutrient content and uptake (NPK) by grain and straw were significantly higher with 75 % RDN + 25 % N poultry manure on par with sole crop compared to other nutrient combinations and control. Organic carbon was also significantly influenced by sole crop on par with 75 % RD N + 25 % N poultry manure and 75% RDN + 25 % N vermicompost over control. Available nitrogen, phosphorus and potassium were found highest with 75 % RD N + 25 % N poultry manure on par with sole crop.

Kar *et al.* (2019) carried out a field experiment to explore the possibilities of successful cultivation of garden pea as intercrop under different spacings of *Grewia*

optiva. Growing of garden pea with the use of 120 % of the recommended doses of nitrogen through vermicompost and poultry manure under 8 m x 3 m spacing of grewia was found better to other treatment combinations with respect to yield, availability of soil nutrients and uptake of nutrients.

2.2.6.3 Effect of organic nutrient management practices in non agroforestry system

The long-term use of inorganic fertilizers without organic supplements changed the soil physical, chemical and biological properties and causes environmental pollution. Organic manures act not only as a source of nutrients and organic matter, but also increases size, biodiversity and activity of the microbial population in soil, influence structure, nutrients turnover and many other related physical, chemical and biological parameters of the soil (Albiach *et al.*, 2000). Most commonly used organic manure is FYM in which cattle dung constitutes the major source of nutrients and but their special merit lies in their capacity to supply large number of essential micronutrients and organic carbon in addition to NPK, which are becoming deficient in the intensively cultivated soils. Similarly, vermicompost enrich the soil by improving the residual build up of organic carbon and available NPK in soil. Vermicompost has many outstanding biological lives like bacteria, actinomycetes, fungi and cellulose degrading bacteria (Werner and Cuevas, 1996). Poultry manure is rich organic manure since solid and liquid excreta are excreted together resulting in no urine loss. In fresh poultry excreta, uric acid or urate is the most abundant N compound (40-70 % of total N) while urea and ammonium are present in small amounts. The fertilizer value of poultry manure was three times higher than the FYM and this was attributed to combined presence of urinary and fecal excretion in the manure. Use of organic manures to meet the nutrient requirement of crop would be inevitable practices in the years to come for sustainable agriculture since, organic manures generally improve the soil physical, chemical and biological properties along with conserving the moisture holding capacity of soil and thus resulting in enhanced crop productivity along with maintaining the quality of crop produce.

Liquid organic manures are the fermented preparations obtained by active fermentation of plant or animal residues. Liquid manure influences the availability of nutrients in soil which is reflected by crop uptake. The use of fermented organics may improve nutrient status and biological activities. Spraying of panchagavya induces quick

flowering, high seed setting percentage and increases the growth and yield components with growth promoting activity.

Vermiwash is a rich source of vitamins, hormones, enzymes, macronutrients and micronutrients when applied to plants help in efficient growth. The comparative study was done on the effect of vermiwash on crop production capacities of soil by improving the physio-chemical properties of soil and reduced the insect-pest infestation which would have facilitated increased uptake of the nutrients by the plants resulting in higher growth and yield. It also helped in sustainable crop production (Verma *et al.*, 2018).

2.2.6.3.1 Effect on growth and yield of crops

Combined uses of vermicompost + vermiwash (5 or 10 %) gave higher fresh yield of vegetable pea plant⁻¹ by approximately 70 per cent over control (Mahto and Yadav, 2005).

Application of organic manures along with panchagavya spray was found effective on many crops than the foliar spray of recommended nutrients and growth regulators at Coimbatore. The superiority of the panchagavya in different crops was noticed with respect to the improvement in growth, yield components and yield of crops than control (Somsundaram and Singaram, 2006).

Reddy *et al.* (2007) found that among three nitrogen sources, application of fresh poultry litter produced highest mean lint yield over the 5 year period (1492 kg/ha) compared with composed poultry litter (1392 kg/ha) and urea (1391 kg/ha). Another study on organic nutrient management practice, application of FYM equivalent to 100% RDN and vermicompost equivalent to 100% RDN recorded higher cotton yield (1021 kg/ha) and on par with recommended chemical fertilizer alone (Sangashetty, 2007). Satyanarayana Rao and Shetty (2007) showed that application of FYM + VC + CR (33 % each) gave the highest seed cotton yield (1469 kg ha⁻¹) which was 18.8 % higher than no manure application.

Shwetha (2007) conducted an experiment to know the effect of nutrient management through organics in soybean wheat cropping system at Main Agricultural Research Station, Dharwad on a medium deep black clay loam soil. Significantly higher leaf area index (LAI), plant height, number of branches, dry matter accumulation, seed

yield and yield parameters like number of pods per plant was noticed with the application of organic manures in combination with fermented organics *viz.*, beejamrut, jeevamrut, panchagavya over alone application of organics.

Amitava *et al.* (2008) reported that vermicompost imparted maximum rice grain yield over all other nutrient sources irrespective of rice varieties in West Bengal.

Deepak *et al.* (2009) reported significant increase in cob, seed and stover yield of maize with the application of 50, 75 and 100 per cent N through biogas slurry and poultry manure. The treatment that received 100 per cent N through biogas slurry and poultry manure resulted in significant increase in cob, seed and stover yield of maize.

Govindappa *et al.* (2009) reported that finger millet applied with poultry manure treatment produced higher grain yield (2970 kg ha⁻¹) than FYM or green manurial treatments (2200–2300 kg ha⁻¹).

Siddaram (2009) concluded that application of 200 per cent RDN equivalent through poultry manure recorded higher rice grain (33.2 q ha⁻¹) and straw yield (37.5 q ha⁻¹) with comparison to control treatment. Similarly, Sangeetha (2009) reported that application of enriched poultry manure compost recorded higher grain yield of rice (4675 and 4953 kg ha⁻¹ in *rabi* 2007 and *rabi* 2008, respectively), which was found to be on par with composted poultry manure (4482 kg ha⁻¹ in 2007 and 4784 kg ha⁻¹ in *rabi* 2008).

Ansari and Sukhraj (2010) study revealed that combination of vermicompost and vermiwash showed a significantly greater yield response of okra by 64.27 per cent as compared with the control. In maize-chickpea sequential systems, it was concluded that the combined application of enriched compost + vermicompost + green leaf manure + panchagavya spray + biodynamic spray at flowering produced significantly higher maize yield (6195 kg ha⁻¹) and application of enriched compost + vermicompost + green leaf manure + panchagavya spray at flowering and 15 days' intervals recorded significantly higher yield of chickpea (1779 kg ha⁻¹) over control (Anon., 2011).

Meena *et al.* (2010) revealed that application of poultry manure @ 150 per cent recommended nitrogen dose gave higher grain yield (5.79 t ha⁻¹) of rice in sandy clay loam soils of Varanasi, Uttar Pradesh. Application of 50 per cent FYM (basal) + 25 per cent vermicompost (basal) + 25 per cent vermicompost as top dressing at 10 days after

transplanting in rice produced the highest grain yield of 4.11 and 4.48 t ha⁻¹, when averaged over the *kharif* and *rabi* seasons, respectively (Barik *et al.*, 2011). Deshpande and Devasenapathy (2011) reported that among combined application of organic manures, green manure + poultry manure recorded highest grain (4148 kg ha⁻¹) and straw yield (6634 kg ha⁻¹) of rice with high yield attributing characters *viz.*, panicle length (20.5 cm), total number of grains panicle⁻¹ (159 and 164 panicle), number of filled grains (149 panicle⁻¹) and lesser sterility (8.99 and 9.26 %) compared to other combinations. Harish and Devasenapathy (2011) reported that application of green manure along with poultry manure recorded highest number of productive tillers m⁻² and panicle weight in rice at the long term organic manurial experimental plot at TNAU, Coimbatore.

Hulihalli *et al.* (2011) obtained significantly higher grain yield (45.8 q ha⁻¹), fodder yield (56.9 q ha⁻¹), grain yield plant⁻¹ (87.2 g), cob length (17.8 cm) and cob diameter (14 cm) and dry matter accumulation (6990.0 kg ha⁻¹) in maize crop with poultry manure @ 1.0 t ha⁻¹ as compared to no-organic manures application and however, it was found on par with vermicompost application @ 2.5 t ha⁻¹.

The mean grain yield of greengram was significantly higher (10.42 q ha⁻¹) with application of organic manures and foliar spray of vermiwash compared to control (Khairnar and Gunjal, 2012).

Enujeke (2013) opined that treatment receiving 30 t ha⁻¹ of poultry manure were superior at 8 weeks after sowing in 2008 and 2009 with mean height of 209.3 cm, mean number of leaves of 13.1, mean leaf area of 682.6 cm², mean grain weight at 16 weeks after sowing of 2.14 t ha⁻¹ and mean number of grains/cob of 518.4 in maize during 2008 and 2009.

Gawade *et al.* (2013) conducted field experiment to assess the effect of organic manures and sources and levels of fertilizers on yield attributes and yield of finger millet (*Eleusine coracana* G.) on lateritic soil. They concluded that crop manured with poultry manure @ 1.32 t ha⁻¹ recorded higher growth and yield of finger millet as compared to control.

At Varanasi, Yadav (2013) studied the effect of organic sources of nitrogen on yield under rice based cropping system and reported that application of 100 per cent RDN

through organic manure (1/3 FYM + 1/3 poultry manure + 1/3 vermicompost) along with biofertilizers recorded the highest grain yield (44.25 q ha⁻¹) of rice.

Prabudoss *et al.* (2014) conducted experiment on kodo millet observed higher growth (plant height, number of tillers hill⁻¹, leaf area index at flowering and dry matter production) and yield attributes (number of panicles hill⁻¹, number of grains panicles⁻¹ and thousand grain weight) and yield (grain and straw) at 125 % RDF, *Azospirillum*, vermicompost and poly feed. The lowest values on growth, yield attributes, yield and economics were recorded at absolute control.

Saunshi *et al.* (2014) application of enriched bio-digester liquid manure (BDLM) with poultry manure and rock phosphate equivalent to 60 kg N ha⁻¹ had led to the significant increase in grain yield (3893 kg ha⁻¹) and straw yield (7228 kg ha⁻¹) of finger millet compared to recommended practice which was in turn due to growth parameters *viz.*, plant height, leaf area index, dry matter production and tillers.

Channagouda (2015) reported that among the organic treatment combinations, combined application of EC (1/3) + VC (1/3) + GLM (1/3) equivalent to RDF with foliar spray of panchagavya @ 5 % recorded significantly higher kapas yield (1999 kg ha⁻¹) and mean boll weight (4.70 g) over other combinations.

Esakkiammal *et al.* (2015) reported that the combination of vermicompost and vermiwash showed maximum positive effects on the growth and yield of lablab beans. Maheswari *et al.* (2019) reported that foliar spray of ten per cent vermiwash and panchagavya along with application of organic manures recorded higher growth, yield parameters and yield of *Dolichos* lablab.

Sreeja (2015) reported that higher grain and straw yields of rice were obtained in the FYM 5.0 t ha⁻¹ + Neem cake 1.0 t ha⁻¹ + Vermicompost 2.0 t ha⁻¹ (Vermicompost at two splits at active tillering and panicle initiation stages) + TNAU Panchakavya (3 %) (4278 and 5324 kg ha⁻¹) over the control (1723 and 2726 kg ha⁻¹).

Alagappan and Venkitaswamy (2016) reported that TRRI practice (poultry manure @ 5 t ha⁻¹ + 1000 kg ha⁻¹ azolla + 8 kg ha⁻¹ azospirillum + 8 kg ha⁻¹ phosphobacteria + 100 kg ha⁻¹ groundnut oil cake on 50 DAT) recorded higher grain yield (5628 kg ha⁻¹ and 5684 kg ha⁻¹ in 2012 and 2013, respectively) and was followed by 100

per cent RDN through green manure (5084 kg ha⁻¹ and 5140 kg ha⁻¹ in 2012 and 2013, respectively), 50% RDN each of through FYM + poultry manure (4721 kg ha⁻¹ and 4833 kg ha⁻¹ in 2012 and 2013, respectively), 50% RDN each of through vermicompost + poultry manure (4923 kg ha⁻¹ and 4986 kg ha⁻¹ in 2012 and 2013, respectively) and 25 % RDN each of through FYM + vermicompost + poultry manure + green manure (5004 kg ha⁻¹ and 5120 kg ha⁻¹ in 2012 and 2013, respectively) in rice.

Debasis Mahata and Ashim Chandra Sinha (2016) opined that treatment receiving vermicompost @ 2.5 t ha⁻¹ + mustard cake @ 2.5 t ha⁻¹ + poultry manure @ 2.5 t ha⁻¹ + FYM @ 4 t ha⁻¹ recorded highest number of cluster plant⁻¹, number of seeds cluster⁻¹ and 1000-seed weight (test weight) in buck wheat compared to control treatment.

Divya Sahare and Babalad (2016) reported that application of 200 per cent RDN equivalent through vermicompost ha⁻¹, 200 per cent RDN equivalent through FYM ha⁻¹, 150% RDN equivalent through vermicompost ha⁻¹ and 100 % RDN equivalent through poultry manure ha⁻¹ recorded significantly higher growth parameters like plant height, number of tillers, leaf area and dry matter production at harvest in aerobic rice compared to control.

Kiran *et al.* (2016) reported significantly higher values of growth and yield parameters and yield of chickpea with the combined application of FYM (50 %) and vermicompost (50 %) equivalent to 100 % RDN than control treatment.

Sanjay *et al.* (2016) reported that 100 % RDN through organic manures as 1/3 FYM + 1/3 poultry manure (PM) + 1/3 vermicompost+ Azotobacter + PSB had the highest rice equivalent grain yield, production efficiency, net energy return, as well as net monetary return and profitability on rice-based cropping sequence.

Sonawane *et al.* (2016) showed that application of 50% N through FYM + 50 % N through vermicompost produced significantly higher values of growth parameters of french bean *viz.*, plant height (44.8 cm), number of branches plant⁻¹ (13.23), plant spread (37.1 cm), number of leaves plant⁻¹ (23.33), leaf area (9.42 dm²) and yield attributes *viz.*, number of pods plant⁻¹ (13.20) and total dry matter plant⁻¹ (43.67 g). The same treatment also resulted in significant increase in seed yield (2.78 t ha⁻¹) and straw yields (5.27 t ha⁻¹) than other treatments.

Ananda and Kalyanamurthy (2017) conducted experiment on farmers field at Chintamani taluka of Doddaballapur district in Karnataka and observed that application of enriched biodigested liquid organic manure (EBDLM) at 50 kg N equivalent ha⁻¹ + 3 sprays of panchagavya (PG) at 3 per cent produced significantly higher grain yield, straw yield, productive tillers plant⁻¹, finger length and 1000 grain weight (3695 kg ha⁻¹, 5169 kg ha⁻¹, 7.33, 9.28 cm and 3.95 g, respectively), LAI, total dry matter production plant⁻¹ and SPAD (2.98, 59.41 g plant⁻¹ and 23.7, respectively) in finger millet than control treatment.

Sunil Kumar *et al.* (2017) reported that among the different organic sources of nitrogen treatments in rice, significantly longest and heaviest panicle was recorded under 100 per cent N through 1/3 vermicompost + 1/3 FYM + 1/3 poultry manure as basal, however, it was found comparable with 100 per cent N through 1/2 poultry manure as basal + 1/2 vermicompost at 30 DAT. The treatment 100 per cent N through 1/3 vermicompost + 1/3 FYM+1/3 poultry manure at basal showed significantly higher number of grains panicle⁻¹ and filled grains panicle⁻¹ as compared to others, but it was at par with treatment 100 per cent N through 1/2 poultry manure as basal + 1/2 vermicompost at 30 DAT.

Ullasa *et al.* (2017) conducted experiment during *Kharif* season of 2016 to study the effect of different organic nutrient management practices on growth, yield and economics of finger millet. Among the different nutrient management treatments, application of recommended dose of FYM along with 100 per cent N equivalent vermicompost recorded significantly higher grain yield (2745 kg ha⁻¹) and straw yield (5166 kg ha⁻¹). Similarly, higher number of tillers at harvest (4.48), lengthier fingers (9.38 cm) and higher yield per plant (14.12 g) were also recorded with same treatment.

Yadava *et al.* (2017) conducted field experiment at MARS, University of Agricultural Sciences, Dharwad, Karnataka state during summer season of 2013-14. Application of EC (1/3) + VC (1/3) + GLM (1/3) equivalent to 50 kg P₂O₅ with FYM recorded significantly higher grain yield of mungbean (1368 kg ha⁻¹) as compared to EC (1/3) + VC (1/3) + GLM (1/3) equivalent to 50 kg P₂O₅ per ha alone (1258 kg ha⁻¹) and was on par with RDF + FYM (1301 kg ha⁻¹).

Upendranaik *et al.* (2018) reported significantly higher plant height (183.11 cm), leaf area (22.60 cm² plant⁻¹), dry matter production (22.08 g plant⁻¹), total number of tillers at harvest (2.73), grain yield (1841 kg ha⁻¹), stover yield of foxtail millet (7066 kg ha⁻¹) and harvest index (0.21) due to application of jeevamrutha + mulching + IFS compost + vermicompost + panchagavya over control.

Kumaran and Parasuraman (2019) conducted field experiment to optimize appropriate nutrient management techniques for tenai (*Setaria italica*) under rainfed ecosystem during *Kharif* season of 2017, at Centre of Excellence in Millets, Athiyandal, Tiruvannamalai District. They reported that basal application of enriched farmyard manure and recommended dose of fertilizer followed by application 3% panchagavya spray at vegetative stage increased the grain yield of tenai (1652.5 kg ha⁻¹) apart from higher leaf area index.

Krupashree (2019) reported that application of Zn and Fe enriched compost + foliar spray of panchagavya recorded significantly higher grain yield of foxtail millet (1262 kg ha⁻¹) and it was found on par with the treatment receiving Zn and Fe enriched vermicompost + foliar spray of ZnSO₄ and FeSO₄ (1232 kg ha⁻¹) and Zn and Fe enriched vermicompost + foliar spray of panchagavya (1137 kg ha⁻¹). These treatments showed their significant superiority over compost application which recorded (695 kg ha⁻¹).

Priya and Sathyamoorthi (2019) while conducting field experiment at Eastern Block Farm of TNAU, Coimbatore during *Kharif* 2015 observed that biogas slurry + 3 % panchagavya spray @ 30, 45 and 60 DAS enhanced the plant height, leaf area index and dry matter production in foxtail millet. The lower plant growth parameters were registered in application of FYM alone. Yield parameters like number of productive tillers m⁻², ear head length and number of grains ear⁻¹ were higher under biogas slurry + 3 % panchagavya spray @ 30, 45 and 60 DAS.

2.2.6.3.2 Effect on soil fertility

The organic matter addition is an indispensable component of soil and plays an important role in maintenance and improvement of soil fertility and productivity. Maintaining high humus content in the soil with appropriate management techniques is key to the improved soil fertility. Proper management of these will make it possible to increase the efficiency of use of soil and added nutrients. Organic carbon content of soil

changes rapidly with addition of organic manures, mobilization and mineralization of nutrients are two important processes that take place simultaneously in soil with addition of organic manures.

The application of poultry manure alone increased the available P (15 kg ha^{-1}) and K (121 kg ha^{-1}) over initial status of 11 and 112 kg ha^{-1} , respectively in boro rice on clay loam soils of Port Blair (Dubey and Verma, 1999).

Singh *et al.* (2005) concluded that application of vermicompost with or without *Azolla* significantly increased the available P as compared to no vermicompost treatments in rice cultivation. The higher availability of soil P observed in treatments receiving vermicompost was attributed to mineralisation of added P on clay soils of Imphal (Manipur, India).

The available NPK status of the post-harvest soil was higher in application of vermicompost @ 5 t ha^{-1} when compared to FYM @ 10 t ha^{-1} in rice (Sudha and Chandini, 2005). Sharma *et al.* (2009) in loamy sand soil of Sonipet observed highest available soil N, P and K (118.0 , 18.5 and 196.0 kg ha^{-1} , respectively) with 100 per cent recommended dose of N through vermicompost with biofertilizer than control under rice-wheat cropping system. Yadav and Kumar (2009) reported that incorporation of various organic manures like compost, FYM, vermicompost and biofertilizer significantly improved the organic carbon content of soil in long term experiment under rice-wheat cropping system. Meena *et al.* (2010) studied the effect of organic nitrogen nutrition on soil health of rice-table pea-onion cropping sequence, found that the values of chemical properties of soil like organic carbon, available N, P and K increased significantly by the application of 150 per cent RDN as vermicompost.

Divya Sahare (2012) reported that among the FYM and vermicompost levels, application of vermicompost at 150 per cent N equivalent recorded significantly higher available nutrient *viz.*, N, P and K in the soil (273.1 , 41.3 and 549.0 kg ha^{-1} , respectively) followed by 125 % RDN as vermicompost (269.6 40.7 and 536.0 kg ha^{-1} , respectively) and lower with RDF applied treatment (190.6 28.0 and 401.3 kg ha^{-1} , respectively) in rice crop. Patil *et al.* (2012) reported that response of chickpea to various organic manures through soil and foliar application of enriched compost (1/3) + vermicompost (1/3) + glyricidia leaf manure (1/3) equivalent to 100 per cent RDN along with foliar spray of 3

per cent panchagavya at flower initiation and 15 days after first spray recorded significantly higher available nitrogen (245 kg ha⁻¹), available phosphorus (25 kg ha⁻¹) and available potassium (357 kg ha⁻¹) in the soil when compared to other treatment combinations involving cow urine, bio-digester and vermiwash solutions.

Pradeep and Sharanappa (2014) observed that application of enriched biodigested liquid manure at 125 kg N equivalent ha⁻¹ + 3 sprays of panchagavya (3 %) to chilli crop had significantly increased the soil available nutrient status like organic carbon, nitrogen, phosphorous and potassium (0.63 %, 377.9, 75.1 and 179.2 kg ha⁻¹, respectively) as compared to the application of biodigested liquid manure at 100 kg N equivalent ha⁻¹ alone.

Basavaraj Kumbar (2016) observed that combined application of FYM at 200 per cent N equivalent + jeevamruta 1000 litres ha⁻¹ and panchagavya at 3 per cent recorded significantly higher soil available nitrogen (400.9 and 450.6 kg ha⁻¹), phosphorus (55.67 and 61.47 kg ha⁻¹) and potassium (299.3 and 332.2 kg ha⁻¹) in frenchbean cultivation during both the years as compared to the control.

Jagadisha *et al.* (2017) reported that application of sewage sludge followed by poultry manure recorded higher nutrient uptake and its availability after harvesting of finger millet when compared with all the treatments.

Vishwajith (2018) revealed that FYM at 200 per cent N equivalent + soil application of jeevamrutha (2000 l ha⁻¹) + foliar spray of panchagavya (5%) recorded higher available nitrogen (342.0 and 382.62 kg ha⁻¹), phosphorus (33.0 and 36.9 kg ha⁻¹) and potassium (250.94 and 273.97 kg ha⁻¹) in okra cultivation as compared to FYM at 100 per cent N equivalent + without jeevamrutha + without panchagavya during both the *Kharif* 2016 and summer- 2017, respectively.

Krupashree (2019) observed higher improvement in soil nutrient status (available N, P₂O₅, K₂O, Zn and Fe) after harvest of foxtail millet with Zn and Fe enriched compost + foliar spray of panchagavya and was found on par with the application of Zn and Fe enriched vermicompost + foliar spray of ZnSO₄ and FeSO₄ and Zn and Fe enriched vermicompost + foliar spray of panchagavya.

2.2.6.3.3 Effect on nutrient uptake

Uptake of nutrients is associated with the metabolic activities of plants and with the concentration and distribution of ions in the external medium. Generally, higher uptake of nitrogen, phosphorus and potassium mainly depends on both economical and biological yield of crops.

Keelara (2001) recorded maximum nitrogen and potassium uptake with the application of poultry manure at 6 t ha⁻¹. Higher residual nitrogen (210.03 kg ha⁻¹) and potassium (320.25 kg ha⁻¹) was also observed in this treatment. Higher N uptake was observed with poultry manure integrated with inorganic fertilizer as compared to inorganic fertilizer alone. Phosphorus uptake had been enhanced by the application of poultry manure in rice.

Significantly higher nitrogen, phosphorus and potassium uptake (124.2, 30.6 and 93.9 kg ha⁻¹, respectively) registered with 200 per cent recommended dose of nitrogen (RDN) equivalent through vermicompost ha⁻¹, 200 per cent RDN equivalent through FYM ha⁻¹, 150 per cent RDN equivalent through vermicompost ha⁻¹ and 100 per cent RDN equivalent through poultry manure ha⁻¹ as compared to the control in irrigated aerobic rice (Siddaram *et al.*, 2010).

Basavaraj Kumbar (2016) reported that combined application of FYM at 200 per cent N equivalent, jeevamruta at 1000 litre ha⁻¹ and panchagavya at 3 per cent recorded higher pod nitrogen (3.71 and 3.77 %), phosphorus (0.072 and 0.076 %) and potassium content (3.29 and 3.37 %) during 2014 and 2015 respectively. Agrawal *et al.* (2016) stated that the treatment receiving vermicompost of soybean stover + cowdung + *trichoderma* + PSB recorded higher uptake of N, P and K *i.e.*, 57.83, 6.45 and 136.8 kg ha⁻¹ over control treatment.

Yadav *et al.* (2017) observed significantly higher total dry matter production in mungbean at harvest was obtained with application of enriched compost (1/3rd) + vermicompost (1/3rd) + glyricidia green leaf manure (1/3rd) equivalent to recommended dose P₂O₅ + FYM (24.18 g plant⁻¹) and among liquid organic manurial treatments, foliar application of panchagavya @ 5 per cent (24.98 g plant⁻¹). The higher uptake of NPK at harvest was significantly higher with application of EC (1/3) + VC (1/3rd) + GLM (1/3rd)

equivalent to 50 kg P₂O₅ + FYM and with panchagavya foliar spray @ 5 % applied at flowering and 15 days after flowering.

Sajal Roy *et al.* (2018) reported that uptake of potassium was higher under intermittent ponding condition in general and the maximum concentration and accumulation was found when poultry manure was incorporated with soil under intermittent ponding condition in rice.

Krupashree (2019) reported that application of Zn and Fe enriched compost + foliar spray of panchagavya recorded significantly higher uptake of NPK in foxtail millet and it was found on par with the treatment receiving Zn and Fe enriched vermicompost + foliar spray of ZnSO₄ and FeSO₄ and Zn and Fe enriched vermicompost + foliar spray of panchagavya. Treatment which received compost alone recorded significantly lower nutrient uptake of N, P, K, Zn and Fe.

2.2.6.3.4 Effect on soil microbial population

Use of organic manures is the object to accelerate microbial processes to enhance availability of nutrients in the assimilable form. Organics modify the micro-climate, alter the environment of soil microbes, enhance soil flora and fauna activity, modify soil moisture regimes and properties associated with it and soil temperature in the root zone. The microbial activities are enhanced as the fresh organic material acts as the nutrient source for the diverse soil flora and fauna. Microbial biomass is the total sum of all micro-organisms present in soil. Organic manures not only supply a higher amount of different nutrient elements but also contains beneficial microbes like nitrogen fixing bacteria, mycorrhizae and growth promoting substances for betterment of crops (Barik *et al.*, 2006).

Application of poultry manure and dhaincha increased bacterial, fungal and actinomycetes population in soil (Boomiraj, 2003 and Somasundaram *et al.*, 2003). The highest bacterial and fungal population was associated with the application of 75 per cent N as vermicompost with *Azospirillum*, which was five times higher than the 100 per cent urea received plot (Kannan *et al.*, 2005).

Yadav and Lourduraj (2007) observed that application of 50 per cent N through composted poultry manure + 50 per cent N through green leaf manure increased

significantly the microbial population and enzymes activity, which was superior to recommended NPK through fertilizers in rice. Application of vermicompost increased total population of N₂ fixing bacteria and actinomycetes. The increased microbial activity improved the availability of soil P and N in rice (Tejada and Gonzaler, 2009). Deshpande *et al.* (2010) found that application of organic manures (FYM, poultry manure, vermicompost and green manure) play an important role in enhancing microbial population *viz.*, bacteria (9.5×10^7 CFU g⁻¹ of dry soil), fungi (5.98×10^4 CFU g⁻¹ of dry soil) and actinomycetes (2.30×10^6 CFU g⁻¹ of dry soil) at harvest of the rice crop as compared to the control.

Significantly higher microbial population *viz.*, bacteria, fungi, actinomycetes, N fixers and P solubilizers (63.6×10^6 , 34.0×10^4 , 53.7×10^4 , 59.2×10^5 and 51.9×10^5 CFU g⁻¹ soil, respectively) was recorded in soil with the application of FYM at 12.5t ha⁻¹ + cattle urine equivalent to 125 kg N ha⁻¹ in rice (Gopakkali, 2010).

Application of poultry manure at 150 per cent recommended nitrogen dose led into higher counts of bacteria (82.4×10^3 CFU g⁻¹ soil), fungi (37.8×10^3 CFU g⁻¹ soil) and actinomycetes (58.2×10^3 CFU g⁻¹ soil) in rice (*Oryza sativa* L.) - table pea (*Pisum sativum* var. *hortense*) - onion (*Allium cepa*) cropping system (Meena *et al.* 2010).

Govindaraju and Reddy (2011) reported that higher microbial activity was observed with application of poultry manure 10 t ha⁻¹ + cattle urine at 5000 l ha⁻¹ to rice crop. Soil rhizosphere had higher population of bacteria (157×10^5 CFU g⁻¹ soil), fungi (88×10^4 CFU g⁻¹ soil), actinomycetes (60×10^3 CFU g⁻¹ soil), N-fixers (96×10^3 CFU g⁻¹ soil) and P-solublizers (72×10^3 CFU g⁻¹ soil) as compared to other levels of poultry manure and cattle urine in rice.

Sharada (2013) recorded that higher population of soil microflora *viz.*, bacteria, fungi, actinomycetes, free living nitrogen fixers and PSB at different growth stages of both greengram and *rabi* sorghum with combined application of organic manures along with panchagavya spray as compared to organic manures application alone.

Pradeep and Sharanappa (2014) observed that application of application of enriched biodigested liquid manure @ 125 kg N equivalent ha⁻¹ + 3 sprays of panchagavya (3 %) to chilli crop had significantly increased microbial population in the

soil bacteria, fungi and actinomycetes (37.0×10^6 , 23.2×10^3 and 13.2×10^3 CFU g⁻¹ soil, respectively) as compared to control.

Alagappan *et al.* (2018) reported that higher bacterial population was recorded with 100 per cent RDN through green manure followed by TRRI practice (poultry manure @ 5 t ha⁻¹ + 1000 kg ha⁻¹, *Azolla* + 8 kg ha⁻¹ *Azospirillum* + 8 kg ha⁻¹, *Phosphobacteria* + 100 kg ha⁻¹ groundnut oil cake on 50 DAT), the lowest bacterial population was recorded with absolute control. Similar trend was also observed with fungal and actinomycetes population in both the years of study after the harvest of rice under rice- greengram cropping system.

Krupashree (2019) indicated that application of Zn and Fe enriched compost + foliar spray of panchagavya recorded significantly higher microbial population in soil of foxtail millet and it was found on par with the treatment receiving Zn and Fe enriched vermicompost + foliar spray of ZnSO₄ and FeSO₄ and Zn and Fe enriched vermicompost + foliar spray of panchagavya. These treatments showed their significant superiority over compost application which recorded. Similar trend was also seen with respect to growth and yield parameters, uptake of nitrogen, phosphorus, potassium, zinc and iron by the crop and also soil microbial populations including beneficial organisms were significantly higher with these treatments.

2.2.6.3.5 Effect on soil enzyme activity

Highest dehydrogenase, urease and phosphatase activity was recorded (Gopal Reddy, 1997) with 100 per cent substitution of RDN using vermicompost, poultry manure, biogas slurry and FYM and it was at par with 50 and 75 per cent substitution, while the treatment receiving only inorganic fertilizers (RDF) recorded the lowest urease activity in maize – soybean cropping system.

Dehydrogenase activity is extensively used as a soil quality indicator (Obbard, 2001) and has been used as a valued bio marker of soil quality under different conditions of agricultural practices. It mainly depends on the metabolic activity state of the soil biota which is significantly correlated with the biomass carbon present in the soil (Garcia *et al.*, 2000). Dehydrogenase activity in the soil is related to a group of enzymes participating in the metabolic reactions producing energy in the form of ATP through the oxidation of organic matter (Tiquia *et al.*, 2002).

Manjunath (2006) observed a marked increase in dehydrogenase activity in the soil of organic farms than that of conventional farms in the selected major cropping system viz., cotton, sugarcane, jowar and vine yard. Similarly, the addition of organic amendments increased the enzyme activity in the rice soils (Gianfreda and Ruggiro, 2006).

Higher dehydrogenase activity was observed under enriched poultry manure compost (28.2 μg of TPF released g^{-1} of soil 24 h^{-1} in *rabi* 2007 and 30.0 in *rabi* 2008) and which was comparable with composted poultry manure and FYM + neem cake. These were followed by enriched FYM compost and enriched FYM compost + vermicompost + FYM, which were on par. The recommended NPK fertilizer registered lower dehydrogenase activity but superior to absolute control in rice (Sangeetha, 2009).

Divya (2012) reported that among the different levels of nitrogen 150 % through vermicompost recorded significantly higher dehydrogenase activity in soil at panicle initiation stage (9.3 mg TPF g^{-1} 24 hrs^{-1}) and at harvest (7.1 mg TPF g^{-1} 24 hrs^{-1}) compared to 100 % RDN through chemical fertilizers (5.1 and 4.5 mg TPF g^{-1} 24 hrs^{-1} , respectively).

Alagappan and Venkitaswamy (2016) reported that higher soil dehydrogenase activity was observed with 100 per cent RDN through green manure (36.8 μg of TPF released g^{-1} of soil 24 h^{-1} in 2012 and 36.9 in 2013) and it was comparable TRRI practice (poultry manure @ 5 t ha^{-1} + 1000 kg ha^{-1} *Azolla* + 8 kg ha^{-1} *Azospirillum* + 8 kg ha^{-1} *Phosphobacteria* + 100 kg ha^{-1} groundnut oil cake on 50 DAT (36.6 and 36.7, respectively) and 25 per cent RDN through each organic manure (36.1 and 35.5, respectively) in rice fields during two years of study.

Biradar *et al.* (2017) revealed that bacteria, fungi, actinomycetes, N fixer and PSB population at different growth stages of frenchbean were significantly higher in PoP + soil application of Jeevamrutha 2000 l/ac at 15, 30 and 45 DAS + foliar application of GSP at 15, 30 and 45 DAS + foliar application of panchagavya 5 % at 15, 30 and 45 DAS (final: $37.67 \times 10^6 \text{ CFU g}^{-1}$, $23 \times 10^4 \text{ CFU g}^{-1}$, $35.33 \times 10^3 \text{ CFU g}^{-1}$, $29.67 \times 10^3 \text{ CFU g}^{-1}$, $28.00 \times 10^3 \text{ CFU g}^{-1}$) compared to initial microbial population ($13.5 \times 10^6 \text{ CFU g}^{-1}$, $10.5 \times 10^4 \text{ CFU g}^{-1}$, $12.45 \times 10^3 \text{ CFU g}^{-1}$, $12.30 \times 10^3 \text{ CFU g}^{-1}$, $13.33 \times 10^3 \text{ CFU g}^{-1}$).

The results indicated that the organic liquid manures have supported the multiplication of different beneficial microbial population in frenchbean crop.

Purva Dubey *et al.* (2018) reported that the 50 per cent nitrogen management through FYM, 50 per cent by poultry manures and application of biofertilizers *Azospirillum* and PSB was found most effective to improve the physico-chemical, biochemical microbial properties of soil and crop yield. Maximum microbial activities like – dehydrogenase activity, basal soil respiration, microbial population – *Azospirillum* and PSB were found under this nutrient management system in rice. Higher soil respiration, dehydrogenase activity and microbial population (*Azospirillum* and PSB) were also recorded in this system.

Rajanand Hiremath (2018) reported that rice-rice-vegetable cowpea with liquid organic manures (*Jeevamrutham* -15 DAP), *Panchagavyam* (30 DAP), Green leaf extract (45 DAP) and fish amino acid (60 DAP) showed the highest soil dehydrogenase activity (60.88 $\mu\text{g TPF formed g}^{-1} \text{ soil day}^{-1}$) followed by the same system without liquid organic manures (59.65 $\mu\text{g TPF formed g}^{-1} \text{ soil day}^{-1}$) and rice-rice-cucumber with liquid organic manures (53.32 $\mu\text{g TPF formed g}^{-1} \text{ soil day}^{-1}$). The lowest dehydrogenase activity (29.62 $\mu\text{g TPF formed g}^{-1} \text{ soil day}^{-1}$) was noticed in rice-rice-fallow.

Sheoran *et al.* (2018) carried out a study to evaluate the impact of management practices on soil biological properties of texturally different soils of Haryana. Surface soil samples were collected from 25 organic farms and their adjoining conventional farms at 11 districts of Haryana. The overall dehydrogenase and phosphatase activities at different locations were found to increase from 35.3 to 56.1 $\mu\text{g TPF g}^{-1} \text{ soil 24 hr}^{-1}$ and from 275.8 to 364.1 $\mu\text{g PNP g}^{-1} \text{ soil}$, respectively under organic farming *i.e.* an increase of 57.5 and 32.01 per cent. Overall a significantly higher microbial biomass carbon (69.1 %) was observed under organically managed soils (274 mg kg^{-1}) compared to conventional (162 mg kg^{-1}). The total bacterial, fungal and actinomycetes counts increased by 56.9, 55.2 and 49.5 per cent, respectively in comparison to those in the conventionally managed soils. The study concluded that soils under organic farming were found to be superior in terms of biological properties than conventionally managed soils which are essential for enhancing soil production and other functions in the given ecosystem.

The organics in combination with liquid organic manures recorded increased microbial activity, higher nutrient availability and maximum nutrient uptake. Combined application of organic manures and liquid organic manure sources, increased the availability of nutrients which ultimately resulted in higher crop uptake, enhanced nutrient efficiency which in turn resulted in better improvement of the growth and yield of crops when compared to their individual application alone.

2.2.6.7 Effect on economics of crop cultivation

Gill and Kamta Prasad (2009) revealed that the application of FYM (1/3rd) + rice straw (1/3rd) + *Glyricidia* leaves (1/3rd) to *Kharif* rice and neemcake (1/3rd) + vermicompost (1/3rd) to *Rabi* cucumber gave highest additional net returns of Rs. 19,485 ha⁻¹ as compared to other nutrient supply stands with the B: C ratio of 1.24 in rice-cucumber cropping system.

Application of 50 per cent N through composted poultry manure + 50 per cent N through green leaf manure along with panchagavya spray recorded higher net returns (Rs. 17,822 ha⁻¹), followed by recommended NPK through panchagavya spray (Rs. 15,586 ha⁻¹) in rice (Yadav and Lourduraj, 2007).

Shwetha (2007) observed that the higher net returns and B:C ratio with combined application of compost + vermicompost + GLM (Rs. 17,167 ha⁻¹ and 2.3, respectively) and which was comparable with that of RDF + FYM (Rs. 17,017 ha⁻¹ and 2.1, respectively) and vermicompost + GLM + beejamrutha + jeevamrutha + panchagavya (Rs. 14,385 ha⁻¹) in soybean-wheat cropping system at UAS, Dharwad.

Siddaram (2009) reported that among different treatments, 100 per cent RDN equivalent through poultry manure ha⁻¹ gave significantly higher benefit cost ratio (2.7) than the control treatment. This may be due to lower cost of cultivation and higher net returns in irrigated aerobic rice. Meena *et al.* (2010) reported that maximum net returns of Rs. 1, 30,799 ha⁻¹ with 1.49 benefit cost ratio was obtained when crops were fertilized with 150 per cent recommended nitrogen dose through poultry manure on sandy clay loam soils of Varanasi, Uttar Pradesh. Rajanna *et al.* (2011) reported that the maximum net return of Rs. 28517 ha⁻¹ was found with poultry manure equivalent to 10 t of FYM + biodigester liquid at 100 per cent N equivalent basis. This is due to lower cost of

cultivation. The lowest net returns of Rs. 11692 ha⁻¹ was recorded with FYM 10 t ha⁻¹ as a basal dose + 100 per cent N equivalent through jeevamritha.

Patil *et al.* (2012) recorded significantly higher B: C ratio (3.69) and net returns (Rs. 48,344 ha⁻¹) with application of enriched compost (1/3) + vermicompost (1/3) + glyricidia leaf manure (1/3) equivalent to 100 per cent RDN along with 3 per cent panchagavya spray at flower initiation and 15 days after flowering of chickpea compared to RDF and other treatments.

Sharma *et al.* (2012) concluded that application of 50 per cent N through vermicompost + 50 per cent N through decomposed organic wastes in bajra gave significantly higher net returns (Rs. 30,625 ha⁻¹) and B: C (2.97) over control (Rs. 43,460 ha⁻¹ and 2.41, respectively).

Basavaraj Kumbar (2016) reported that application of FYM at 200 per cent N equivalent + jeevamrutha at 1000 l ha⁻¹ + panchagavya 5 per cent recorded higher gross returns (Rs. 4,56,650 ha⁻¹ and Rs. 7,57,112 ha⁻¹), net returns (Rs. 3,19,809 ha⁻¹ and Rs. 6,17,271 ha⁻¹) and B:C ratio (3.34 and 5.41) as compared to application of FYM at 100 per cent N equivalent + without jeevamrutha + without panchagavya *i.e.*, gross returns (Rs. 2,41,314 ha⁻¹ and Rs. 3,60,414 ha⁻¹), net returns (Rs. 1,59,729 ha⁻¹ and Rs. 2,73,129 ha⁻¹) and B:C ratio (2.96 and 4.13) in frenchbean cultivation during 2014 and 2015, respectively.

Satyanarayana Rao *et al.* (2017) carried out investigation from 2012-13 to 2014-15 at MARS, Raichur, India to develop organic nutrient schedule in greengram - rabi sorghum cropping system under rainfed conditions. The pooled results indicated that yields realized from both the crops and net returns of the whole system with RDF were on par with Compost + Vermicompost + Panchagavya and Compost + Vermicompost + Green Leaf Manure + Panchagavya which showed promising in organic cultivation of greengram and rabi sorghum.

Significantly higher gross return (Rs. 75503 ha⁻¹) and net return (Rs. 42903 ha⁻¹) of finger millet was recorded with 100 per cent N equivalent vermicompost along with recommended FYM. However significantly higher B: C ratio of 2.50 was recorded with application of 125 per cent of N equivalent vermicompost alone (Ullasa *et al.*, 2017).

Vishwajith (2018) reported that application of 200 per cent N equivalent through FYM + jeevamrutha at 2000 l ha⁻¹ + panchagavya 5 per cent recorded higher gross returns (Rs. 3,52,450 ha⁻¹ and Rs. 3,96,900 ha⁻¹), net returns (Rs. 2,11,306 ha⁻¹ and 2,51,186 ha⁻¹), benefit cost ratio (2.50 and 2.72) with okra crop during 2016 and 2017 seasons.

The highest gross returns (Rs. 56,996 ha⁻¹) and net returns (Rs. 39,846 ha⁻¹) of foxtail millet cultivation was obtained with jeevamrutha + mulching + IFS compost + vermicompost + panchagavya and minimum with control treatment. This treatment was followed by jeevamrutha + mulching + IFS compost + panchagavya and IFS compost + panchagavya (Upendranaik *et al.*, 2018). Krupashree (2019) recorded higher net returns and B: C ratio from foxtail millet cultivation with the application of Zn and Fe enriched compost + foliar spray of panchagavya (Rs. 27185 ha⁻¹ and 2.83, respectively) and was found on par with the application of Zn and Fe enriched vermicompost + foliar spray of ZnSO₄ and FeSO₄ (Rs. 25522 ha⁻¹ and 2.62, respectively) and Zn and Fe enriched vermicompost + foliar spray of panchagavya (Rs. 21897 ha⁻¹ and 2.44, respectively).

The combined application of organic manures and liquid organics improved nutrient efficiency which in turn resulted in better improvement of the growth and yield of crops when compared to their individual application alone. Organic foxtail millet production helped to sustain and minimize external dependency on agricultural inputs.

2.3 Performance of tree species under high density planting system

The choice of planting density is a primary agroforestry decision in plantation management which considers the trade-off between individual tree size and total stand production, affecting the type, quantity and quality of products throughout the rotation.

Bhardwaj *et al.* (2001) conducted experiment on *Populus deltoides* with three densities *viz.*, 60 cm x 60 cm, 90 cm x 90 cm and 120 cm x 120 cm under rainfed conditions in mid hill zone of Himachal Pradesh. The plantation harvested after 13 years, produced maximum biomass (218.08 t ha⁻¹) in the closest spacing of 60 cm x 60 cm for which the bole contributed 90.71 per cent of the total above ground biomass accumulation. The nutrient accumulation in the biomass differed with tree density. The maximum nutrient content was present in the closest spacing. They also reported that organic carbon content in the soil decreased with the decrease in tree density. The nutrient

return through litter fall was less in closer spacing as compared to the total uptake which created nutrient deficit in the soil.

Khan and Chaudhary (2007) studied the effect on performance of poplar AY-48 at a spacing plant density of 455, 305 and 230 trees ha⁻¹ under agroforestry system. Poplar trees put significantly greater diameter (DBH) growth under the spacing of 3.7 x 12.1 m. At the spacing of 3.7 x 12.1 m and density of 230 trees ha⁻¹, 72.2 per cent trees were found in bigger DBH class of 30.6-35.5 cm while only 23.2 and 27.3 per cent trees were able to touch this DBH class under higher density of 305 trees ha⁻¹ at a spacing of 3.7 x 12.1 m and 3.7 x 9.1m, respectively.

Pant *et al.* (2010) evaluated performance of *Populus deltoides* under three spacings (Open, 5 m x 4 m and 5 m x 3 m). The average relative illumination below 5 m x 4 m and 5 m x 3 m poplar spacing was 48 and 40 per cent respectively. Nithiya Kalyani (2010) noticed highest organic carbon content is (0.66 %) in 6 m x 4 m and 5 m x 5 m spacing of *Bambusa vulgaris*. The highest available nitrogen was found to be 255.6 kg ha⁻¹ at 6 m x 6 m spacing. The highest available phosphorous 33.1 kg ha⁻¹ and available potassium 329.6 kg ha⁻¹ were recorded at 7 m x 4 m spacing.

Patil *et al.* (2012) conducted a field trial on *Melia azedarach* based agroforestry system. The experiment consisted four spacings *viz.*, 5 m x 1m, 5 m x 2 m, 5 m x 3 m and 5 m x 4 m. The net returns and B: C ratios were significantly higher in *Melia azedarach* at spacing of 5 m x 4 m followed by at 5 m x 3 m as compared to the other treatments.

Forrester *et al.* (2013) reported that *Eucalyptus globulus* plantations on five site qualities (122–435 m³ ha⁻¹) planted at six densities (625 trees ha⁻¹, 4 m x 4 m; 833 trees ha⁻¹, 3 m x 4 m; 1000 trees ha⁻¹, 4 m x 2.5 m; 1250 trees ha⁻¹, 4 m x 2 m; 1667 trees ha⁻¹, 3 m x 2 m; and 2000 trees ha⁻¹, 3 m x 1.75 m) were used to investigate this interaction. Mean tree diameter of the whole stand and the basal area of the largest diameter were higher at lower planting densities, whereas whole stand basal area was greater at higher planting densities.

Dutt and Thakur (2014) calculated monetary status of cropping systems for two consecutive years under Shivalik Ranges of outer Himalayas, combining medicinal and aromatic herbs with commercial timber species. Four herbal crops namely *Ocimum sanctum*, *Spilanthes acmella*, *Tagetes minuta* and *Withania somnifera* were intercropped

with 6 year old plantation of *Populus* hybrid (G-48) having 8 x 3 m, 6 x 4 m, 5 x 5 m and 4 x 6 m spacing. Among different spacing, 8 x 3m and 6 x 4 m spacing excelled over 5 x 5 m and 4 x 6 m spacing, which ensured significantly higher net returns from the combination.

Prasad *et al.* (2015) while studying the effect of tree density (1 x 1 m, 1.3 x 1.3 m, 3 x 0.75 m, 3 x 1 m, 5 x 0.8 m and 3 x 2 m corresponding to a tree density of 10,000, 6666, 4444, 3333, 2500 and 1666 ha⁻¹) on the growth, biomass partitioning and wood productivity of *Leucaena leucocephala* at Andhra Pradesh observed that at 51 months after planting, spacings significantly influenced tree height, diameter at breast height (DBH), number of branches and biomass partitioning. Wider tree rows resulted in greater tree height and diameter growth resulting in higher per plant productivity. At harvest, 70 per cent of trees in 3 m x 2 m attained a diameter of more than 7.5 cm, while 35 per cent of the trees attained the same DBH in 1 m x 1 m spacing. Increased spacing levels decreased the relative amount of growth allocated to the bole of the tree. Marketable biomass yield was highest with 1 x 1 m spacing. Spacing of 3 m x 0.75 m produced marketable biomass comparable to that of 1 x 1 m and greater proportion of stems with more than 5 cm diameter. *Leucaena* can be grown at 3 x 0.75 m spacing either for pulpwood or fuelwood depending on the prevailing market prices and demand.

Pradeep (2015) reported that planting geometry of *Melia dubia* at 24 m x 5 m was significantly superior in terms of its tree height (10.73 m), biomass (44.41 t ha⁻¹), bole height (3.96 m), GBH (62.40 cm), collar diameter (78 cm), canopy spread towards north-south (8.40 m), towards east-west (5.46 m), volume (0.097 m³) and biomass (44.41 t ha⁻¹) as compared to other planting geometry. Kirankumar and Patil (2017) conducted experiment on growth and productivity of *Melia dubia* under different planting densities at AICRP on Agroforestry, UAS, Dharwad and results revealed that the planting densities of 833 trees ha⁻¹ and 1000 trees ha⁻¹ showed optimum performance over the individual tree performance as well as total stand performance. The planting density of 2500 trees ha⁻¹ exhibited significant stand volume compared to other planting density. In another trial, Patil *et al.* (2017) observed significant difference among different planting densities of *Melia dubia* and maximum tree girth (cm) and height (m) was recorded in planting density of 714 trees ha⁻¹ (46.85 cm, 10.59 m; 50.14 cm, 10.99 m; 52.99 cm, 11.22 m and 55.76 cm, 11.43 m, respectively) for all the time interval. However, the total stand volume

in the entire time interval was significantly superior in case of planting density of 2500 trees ha⁻¹ (125.0 m³ ha⁻¹, 148.3 m³ ha⁻¹, 165.8 m³ ha⁻¹ and 189.25 m³ ha⁻¹).

Zahabu *et al.* (2015) examined the effects of planting geometry on growth, yield and wood properties of teak planted at square spacing regimes of 2 m, 3 m, and 4 m at Longuza Forest Plantation, Tanzania and reported that diameter at breast height and total height increased with wider spacing. Mean annual increment increased significantly with increasing spacing, while, spacing did not have significant effect on total volume production and basal area. However, the use of a spacing of 4 x 4 m gave at least 50 per cent heart wood at shorter rotation age of 30 years.

Rocha *et al.* (2016) studied the wood density of clones of *Eucalyptus grandis* × *E. camaldulensis* grown in five different plant spacings, namely, 1.5, 3.0, 4.5, 6.0 and 9.0 m² (representing 3.0 m x 0.5 m, 3.0 m x 1.0 m, 3.0 m x 1.5 m, 3.0 m x 2.0 m and 3.0 m x 3.0 m, respectively) in Itamarandiba, Northern Minas Gerais, Brazil. Trees planted at 4.5 to 9.0 m² spacings had wood density approximately 8 per cent higher than the same clones planted in narrow spacing (1.5 m²).

Guangyou *et al.* (2016) studied the dynamic change of tree height, DBH and stand volume in different density/spacing treatments, the relationship between DBH and crown width, the basic density management for 5.9 year old *E. urophylla* plantation in Laibin County of Guangxi, China. The results indicated that plantation density had a negative correlation with height, DBH and standing volume growth. The superiority order of the density treatments in stand volume was 1667>2222>3333 trees ha⁻¹. After 3.7 years, spacing 2 m x 3 m performed better in height growth than 1 m x 6 m. The best treatment was 1667 trees/ha with stand volume 2.04 times of that of 3333 trees ha⁻¹. Three spacing treatments ranked in stand volume in order of 1667>2222>3333 trees ha⁻¹ at 4.7 year old but 2222>1667>3333 trees ha⁻¹ at 5.9 year old. The treatment of density 2222 trees ha⁻¹ yielded 127.6 m³ ha⁻¹, 1.17 times as much as that of 3333 trees ha⁻¹.

Kar *et al.* (2019) carried out field experiment observed that tree growth, biomass, net revenue and B:C ratio of *Grewia optiva* under 8 m x 3 m spacing was found better to other other levels of spacings.

MATERIAL AND METHODS

III. MATERIAL AND METHODS

Field experiments on “Agronomic manipulations for productivity and income enhancement in *Melia dubia* Cav. based agroforestry system under organic production” during 2018-19 and 2019-20 were carried out at Santhekellur village (Farmer field) and Biofuel Park ARS, Tinthani at University of Agricultural Sciences, Raichur (UAS, Raichur). The detailed information on different materials used and techniques adopted during the course of investigations are presented in this chapter.

3.1 Location of the experimental sites

The present investigation comprised the survey, an experiment in shadenet and two field experiments. The details of these were furnished below.

Sl. No	Title	Location
1	Survey on performance of <i>Melia dubia</i> in agroforestry system on farmers field in Kalyana Karnataka region	Kalyana Karnataka region (UAS, Raichur, jurisdiction)
2	Effect of pre-sowing seed treatment on germination of <i>Melia dubia</i>	Biofuel Park, ARS, Tinthani (Shorapur taluka of Yadgiri district) which is situated between latitude of 17° 33' N and longitudes of 76° 85' E with a mean sea level of 389 m.
3	Performance of foxtail millet as influenced organic nutrient management practices in <i>Melia dubia</i> based agroforestry system	Farmer's field (Sri Somasekhar) in Santhekellur village of Lingsugur taluka in Raichur district, which is situated between latitude of 15° 99' N and longitude of 76 ° 66' E with a mean sea level of 499 m.
4	Early growth performance of <i>Melia dubia</i> under high density planting system	Biofuel Park, ARS, Tinthani (Shorapur taluka of Yadgiri district)

3.2 Soil characters of the experimental sites

The soil of the experimental site at Santhekellur village was medium black and Biofuel Park, ARS, Tinthani, it was red sandy soil. Composite soil samples were collected from experimental site from top 0 to 30 cm depth before the layout. The soil samples were analyzed for their physical, chemical and biological properties and the data along with methods employed for their estimation are furnished in Table 1.

Table 1. Soil physical, chemical and biological properties of experimental sites

Sl.No	Particulars	Value obtained at Santhekel lur village	Value obtained at Biofuel Park, ARS Tinthani	Method adopted
I	Physical properties			
1	Particle size distribution			
a	Sand (%)	23.68	48.55	International pipette method (Piper, 1966)
b	Silt (%)	22.83	17.25	
c	Clay (%)	53.49	34.20	
II	Chemical properties			
1	Soil pH	7.61	7.30	1:2.5 soil water suspension with the help of digital pH meter (Jackson, 1973)
2	Electrical conductivity (dSm ⁻¹)	0.22	0.51	1:2.5 soil water suspension using conductivity bridge (Jackson, 1973)
3	Organic carbon (%)	0.41	0.37	Walkley and Black rapid titration method (Walkley and Black, 1934)
4	Available nitrogen (kg ha ⁻¹)	243.20	146.26	Alkaline potassium permanganate method (Subbaiah and Asija (1956)
5	Available phosphorus (kg ha ⁻¹)	26.30	14.59	Spectrophotometric method (Olsen Extraction method with 0.5 M NaHCO ₃ , pH of 8.5) (Jackson, 1973)
6	Available potassium (kg ha ⁻¹)	331.56	236.60	Flame-photometric method (Extraction with N NH ₄ OAc of pH 7) (Jackson, 1973)
III	Biological properties			
1	Bacteria population (10 ⁶ cfu g ⁻¹ soil)	18.25		Soil dilution and plate count method (Pramer and Schmidt, 1964)
2	Fungal population (10 ⁴ cfu g ⁻¹ soil)	16.10		
3	Actinomycetes population (10 ³ cfu g ⁻¹ soil)	15.52		
4	Alkaline phosphatase (µg PNP cfu g ⁻¹ soil h ⁻¹)	85.54		Evazi and Tabatabai (1979)
5	Dehydrogenase (µg TPF g ⁻¹ soil day ⁻¹)	8.47		

3.3 Climatic conditions of the experimental sites

Santhekellur village falls under Lingsugur taluka of Raichur district in Northern Dry Zone (Zone-3) of Karnataka, while, Biofuel Park, ARS, Tinthani falls under Shorapur taluka of Yadgiri district in North - Eastern Dry zone (Zone- 2) of Karnataka. Both locations are situated within 30 km range and have similar climatic conditions. The mean monthly meteorological data of rainfall, temperature and relative humidity recorded at Raitha Samparka Kendra (RSK), Maski which is nearer (8 km) to Santhekellur and Kakkera, which is nearer (5 km) to Biofuel Park, ARS, Tinthani during period of 2018-19 and 2019-20 are furnished in Table 2 and 3 and depicted in Fig. 1 to 4.

3.4 Experimental details

3.4.1 Experiment - I: Survey on performance of *Melia dubia* in agroforestry system on farmers' field in Kalyana Karnataka region

Survey on performance of *Melia dubia* in agroforestry system on farmer's field and perception of farmers towards adoption and non adoption of *Melia dubia* was conducted in 38 farmers field in Kalyana Karnataka region (UAS, Raichur, jurisdiction) by developing questionnaire (Annexure I a, I b and I c). Growth observations on tree height, bole height, diameter at breast height (DBH) and collar diameter and economic yield as per the age of the tree were recorded in all farmer's field. The method of recording these observations was followed as per the details given in experiment III and IV of this chapter.

3.4.2 Experiment-II: Effect of pre-sowing seed treatment on germination of *Melia dubia*

The experiment was conducted during 2018-19 and 2019-20 at Biofuel Park, ARS, Tinthani under shadenet.

3.4.2.1 Treatment details

T₁ : Absolute control

T₂ : Soaking of seeds in Cold water (4 days)

T₃ : Soaking of seeds in Cold water (8 days)

T₄ : Soaking of seeds in Cold water (12 days)

T₅ : Soaking of seeds in Cowdung slurry (4 days)

Table 2. Monthly meteorological data recorded for the experimental period (2018-19 and 2019-20) and mean of the last 29 years (1989-2017) at RSK, Maski (Raichur district)

Months	Rainfall (mm)			Temperature (°C)				Relative humidity (%)			
	2018	2019	Average (1989-2017)	Maximum		Minimum		Maximum		Minimum	
				2018	2019	2018	2019	2018	2019	2018	2019
January	0.0 (0)	02.0(0)	0.0	30.99	29.11	16.25	14.23	84.67	74.5	43.19	27.79
February	0.0 (0)	01.0(0)	0.0	32.74	33.58	17.33	18.99	58.19	62.78	15.43	20.42
March	0.0 (0)	08.0(0)	0.0	36.51	37.27	21.75	23.05	54.97	54.11	14.85	14.03
April	21.0(1)	19.0(2)	7.0	38.47	39.22	25.47	25.63	73.70	57.41	28.42	12.92
May	45.0 (6)	35.4(3)	56.5	39.03	39.45	26.20	26.16	81.32	64.65	32.06	15.48
June	41.5 (5)	78.1(6)	82.0	33.61	34.89	24.01	24.13	93.97	78.72	52.80	33.92
July	97.0 (3)	58.1(8)	20.5	31.59	31.09	23.74	22.61	92.93	84.54	58.02	46.87
August	53.5 (7)	78.5(9)	48.0	31.08	29.63	22.88	22.38	94.10	87.05	59.20	52.99
September	192.0 (6)	138.0(11)	78.5	32.56	29.79	22.86	21.93	94.79	92.25	54.78	57.00
October	74.0 (3)	111.0(6)	108	32.32	28.93	20.83	21.48	94.30	96.33	47.09	62.65
November	15.0 (0)	23.4(1)	3.5	30.78	28.69	18.86	18.96	84.53	94.91	40.93	53.14
December	2.00(0)	05.0(0)	0.0	29.38	27.26	17.23	16.79	81.59	95.02	38.62	51.70
Total/Av	404.0 (31)*	541.0 (46)*	557.5	33.26	32.41	21.45	21.36	82.42	78.52	40.45	37.41

* Figures in the parenthesis indicate the number of rainy days.

Source: KSNDMC, Bengaluru

Table 3. Monthly meteorological data recorded for the experimental period (2018-19 and 2019-20) and mean of the last 29 years (1989-2017) at RSK, Kakkera (Yadgiri district)

Months	Rainfall (mm)			Temperature (°C)				Relative humidity (%)			
	2018-19	2019-20	Average (1989-2017)	Maximum		Minimum		Maximum		Minimum	
				2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
April	45.50	37.50	14.45	39.55	41.10	25.35	26.96	72.78	65.56	25.73	19.95
May	48.00	21.00	30.33	40.65	41.96	26.38	27.62	77.25	68.73	28.39	21.75
June	56.00	152.50	52.47	34.94	36.28	24.53	25.24	87.29	86.31	48.94	45.57
July	25.00	68.00	69.34	33.12	33.22	24.01	24.43	88.69	88.20	54.67	55.64
August	49.00	69.00	113.96	32.45	32.43	23.55	24.12	89.95	89.55	57.69	57.68
September	65.00	90.00	123.98	33.59	31.87	22.70	23.57	91.05	91.46	51.93	58.24
October	65.00	60.00	85.85	34.06	31.62	22.14	23.08	85.68	95.18	41.22	61.36
November	1.00	10.00	16.13	32.83	32.18	20.32	21.28	83.20	93.67	41.20	53.27
December	1.00	0.00	2.43	30.70	30.43	18.72	19.85	83.68	92.71	46.27	52.50
January	0.00	0.00	4.42	31.30	31.70	15.96	19.83	78.80	88.74	32.38	45.64
February	0.00	0.00	0.27	34.79	33.36	20.50	20.43	67.45	81.02	28.08	36.53
March	2.00	5.00	6.88	38.71	36.43	23.99	22.74	60.81	73.48	21.87	28.73
Total/Av	357.50	513.00	520.51	34.72	34.38	22.35	23.26	80.55	84.55	39.86	44.74

Source: KSNDMC, Bengaluru

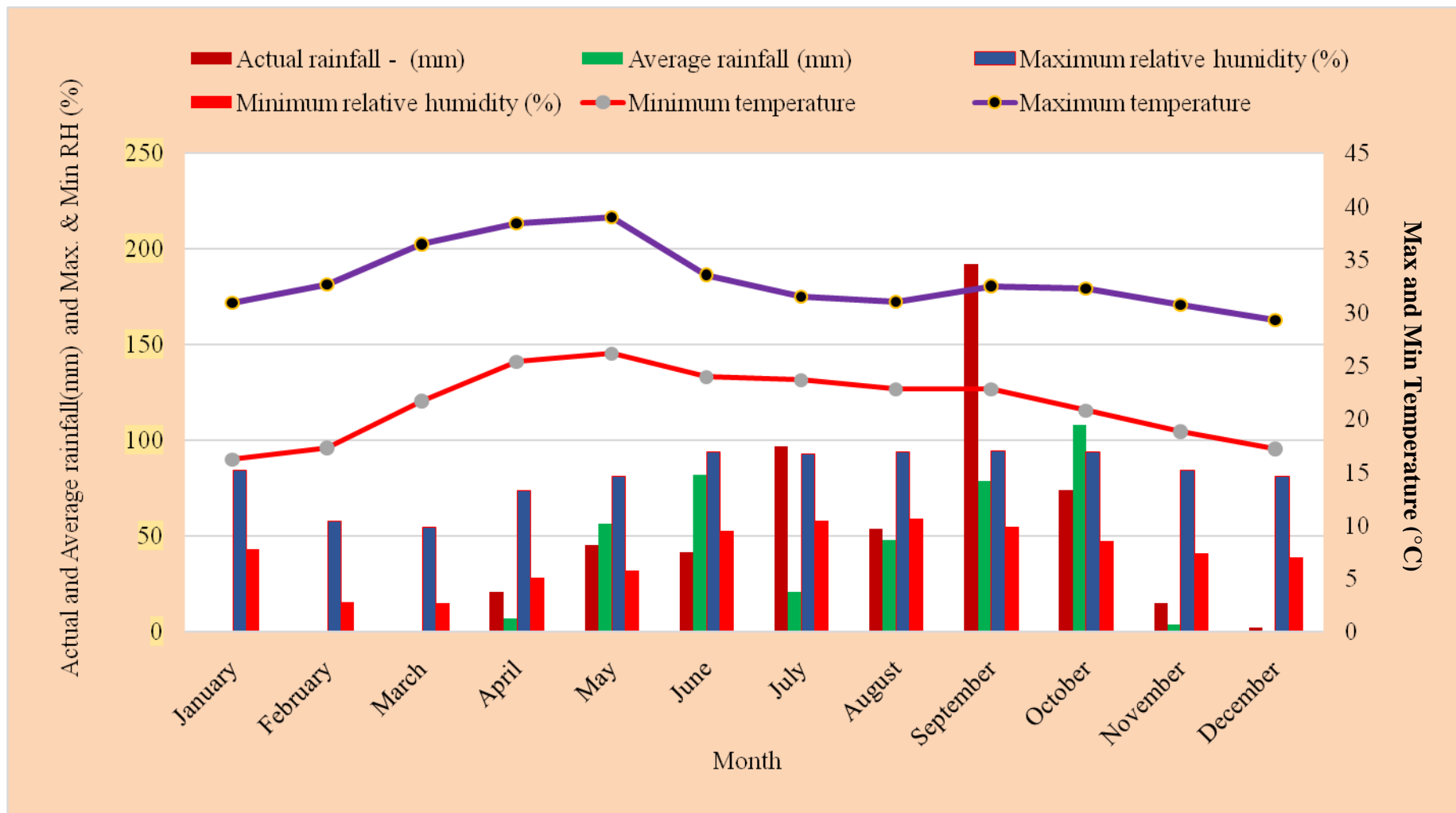


Fig. 1. Monthly meteorological data recorded during the experimental period (2018) and mean of the last 29 years at RSK, Maski (Raichur district)

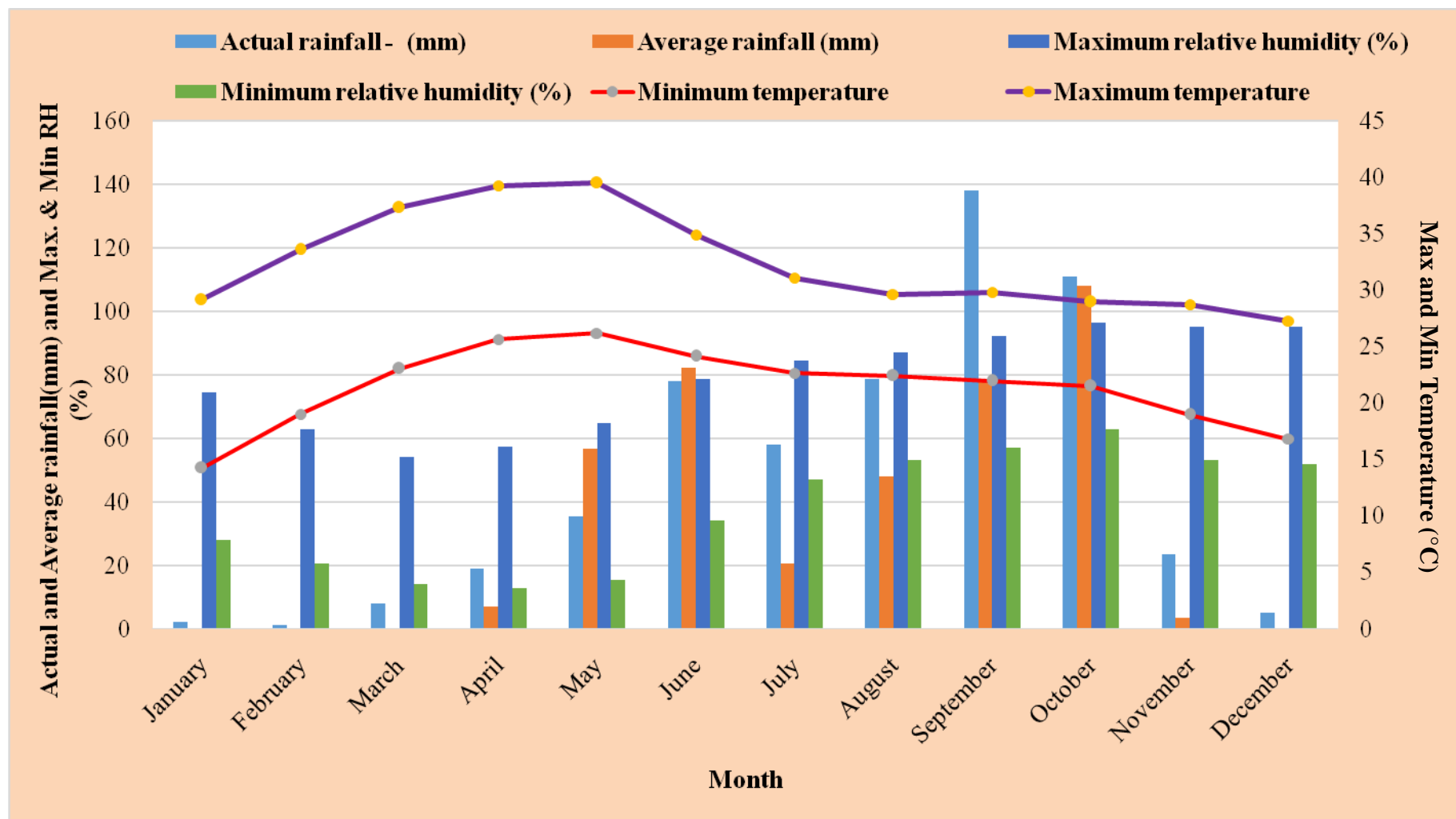


Fig. 2. Monthly meteorological data recorded during the experimental period (2019) and mean of the last 29 years at RSK, Maski (Raichur district)

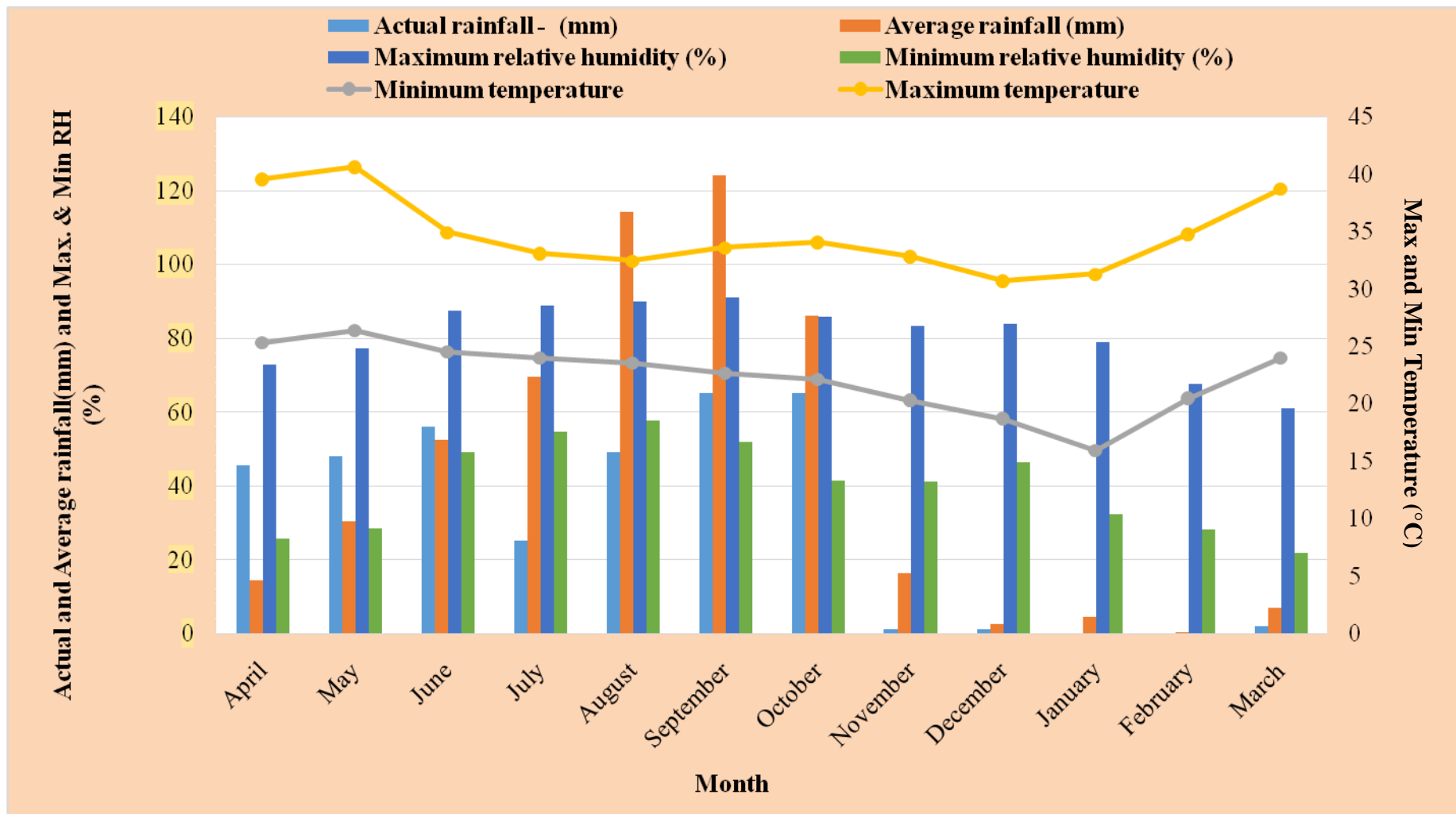


Fig. 3. Monthly meteorological data recorded for the experimental period (2018-19) and mean of the last 29 years (1989-2017) at RSK, Kakkera (Yadgiri district)

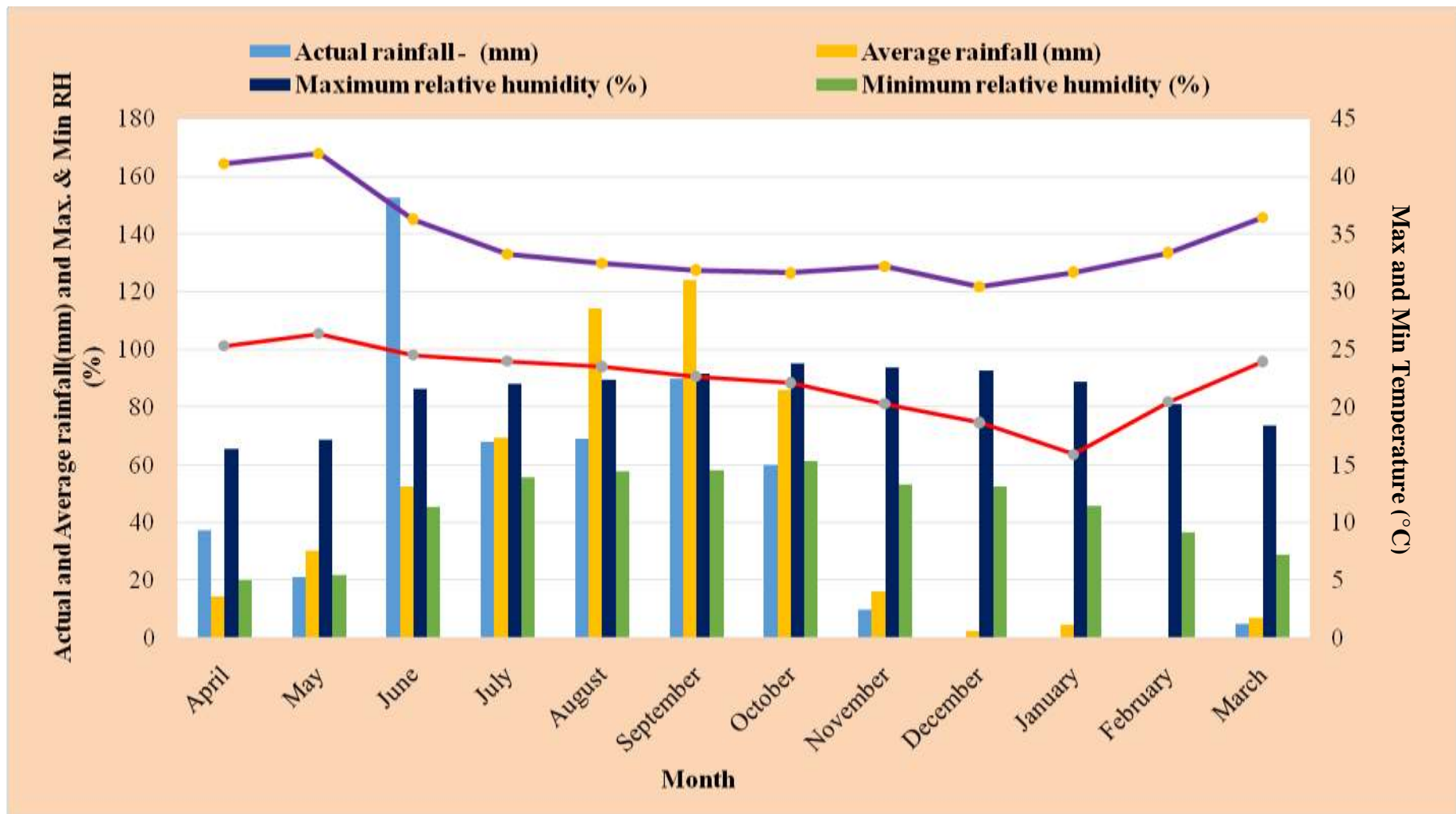


Fig. 4. Monthly meteorological data recorded for the experimental period (2019-20) and mean of the last 29 years (1989-2017) at RSK, Kakkera (Yadgiri district)

T₆ : Soaking of seeds in Cowdung slurry (8 days)

T₇ : Soaking of seeds in Cowdung slurry (12 days)

T₈ : Soaking of seeds in Biogas slurry (4 days)

T₉ : Soaking of seeds in Biogas slurry (8 days)

T₁₀: Soaking of seeds in Biogas slurry (12 days)

T₁₁: Soaking of seeds in KNO₃ solution (200 m moles for 24 hrs)

3.4.2.2 Methodology adopted

The uniform sized *Melia dubia* seeds were chosen for the germination trial under shadenet. Fifty four randomly selected seeds were used for each treatment. There were eleven treatments comprising seed treatment with cold water, cowdung slurry, biogas slurry and KNO₃ solution along with control. Soaking of seeds for different periods were made as per the treatments. All the treatments were timed in such a way that period of soaking practices ended at the same time. Later, the seeds of each treatment were sown in plastic trays on 02.03.2019 and 11.10.2019 during 2018-19 and 2019-20, respectively for germination test. Aftercare operations *viz.*, watering and weeding were done as and when required during the experimental period.

3.4.2.3 Design and layout

The experiment was conducted in Completely Randomized Design (CRD) under shadenet. The plan of layout of the experiment was depicted in Fig. 5.

3.4.2.4 Collection of data

Seed germination test was carried out by adopting sand media germination method as per the procedures of ISTA (Anon., 1996). The number of *Melia dubia* seeds germinated in each day was counted and emergence of plumule was taken as the criterion of germination. The germination percentage was recorded up to 75 days from the day of sowing of seeds. Based on germination count, the following parameters were computed.

3.4.2.4.1 Imbibition period (day)

Imbibition period was calculated by number of days from sowing to commencement of germination.

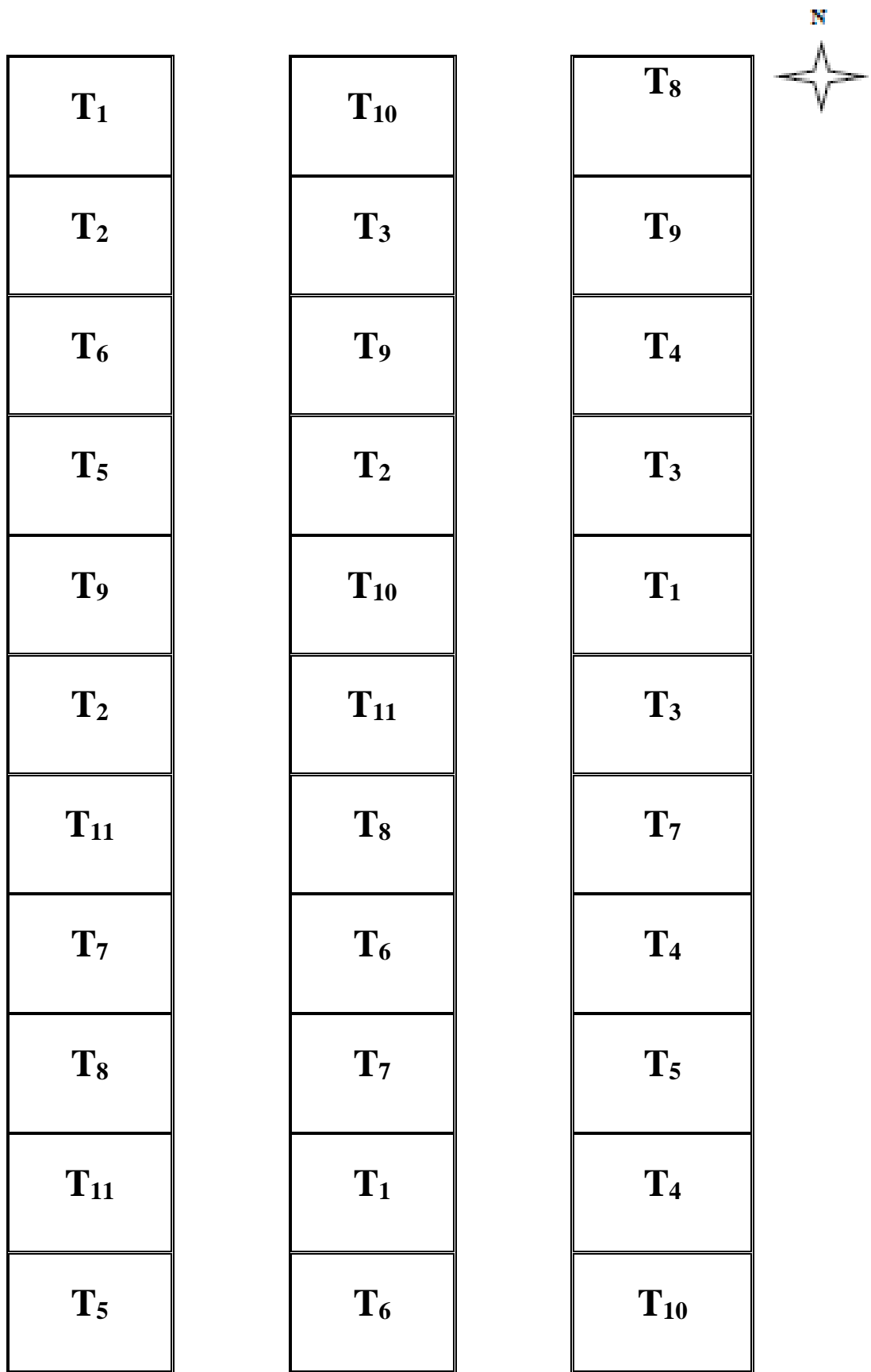


Fig. 5. Plan of layout of the experiment - II

3.4.2.4.2 Total germination period (day)

Total germination period was calculated based on total number of days required for peak germination.

3.4.2.4.3 Germination (%)

The number of normal seedlings was counted on 75th day of germination (final count) in all the treatments. The germination percentage was worked out by using the following formula.

$$\text{Germination (\%)} = \frac{\text{Total number of seeds germinated}}{\text{Total number of seeds sown}} \times 100$$

3.4.2.4.4 Germination value (GV)

It is a composite value that combines both germination speed and total germination which provides an objective means of evaluating the results of germination test. Germination value was calculated from the formulae given by Czabator (1962).

$$\text{Germination value} = \text{Mean daily germination} \times \text{Peak value}$$

3.4.2.4.5 Germination energy (%)

The germination energy was calculated by dividing cumulative germination per cent by the time elapsed since sowing date when it reached its peak.

3.4.2.4.6 Shoot length (cm)

The height of the seedlings was measured from collar region to the apex in three randomly selected normal seedlings at the end of germination period (75th day) and the mean was recorded as seedling height in centimeters (cm).

3.4.2.4.7 Root length (cm)

The root length of the seedlings was measured from collar region to tip of the root in three randomly selected normal seedlings at the end of germination period (75th day) and the mean was recorded as root length in centimeters (cm).

3.4.2.4.8 Total seedling length (cm)

The total length of the seedlings was measured by adding shoot and root length and expressed in centimeter (cm).

3.4.2.4.9 Collar diameter (mm)

Collar diameter (mm) of seedlings was measured at collar region in three randomly selected normal seedlings at the end of germination period (75th day) and the mean was recorded as collar diameter of seedlings expressed in millimeters (mm).

3.4.2.4.10 Number of leaves per seedling

Total numbers of leaves from three randomly selected seedlings were counted at the end of germination period and the mean was recorded as numbers of leaves per seedling.

3.4.2.4.11 Shoot dry weight (g plant⁻¹)

Three seedlings from each treatment were selected for separation of shoots and separated shoots were oven dried at 65^o C to a constant weight was attained. Dry weight of shoots was weighed and mean was recorded as shoot dry weight (g).

3.4.2.4.12 Root dry weight (g plant⁻¹)

Three seedlings from each treatment were selected and later roots were separated. Separated roots were oven dried at 65^o C to a constant weight was attained. Dry weight of root was weighed and mean was recorded as root dry weight (g).

3.4.2.4.13 Total dry weight (g plant⁻¹)

Total dry weight of seedling was calculated by adding shoot and root dry weight, expressed in gram (g).

3.4.2.3.14 Vigour Index

Vigour Index was calculated by adopting the method suggested by Abdul Baki and Anderson (1973) and expressed as number.

Vigour Index = Germination percentage x Total length of seedling

3.4.3 Experiment - III: Performance of foxtail millet as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

The experiment was conducted with eleven treatments comprising of different nutrient management practices through organics on farmer field of Santhekellur village in existing *Melia dubia* based agroforestry plantation system with foxtail millet (*Setaria italica*) as an intercrop and sole crop (without tree) under rainfed conditions. The experiment was laid out in five years old *Melia dubia* plantation spaced at 9 m x 3 m under organic field which has been in practice for 12 years since 2006.

3.4.3.1 Treatment details

T₁ : No organic manure (Control)

T₂ : FYM equivalent to 100 % RDN

T₃ : FYM (50%) + Vermicompost (50%) equivalent to 100 % RDN

T₄ : FYM (50%) + Poultry manure (50%) equivalent to 100 % RDN

T₅ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₆ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₇ : **T₃** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₈ : **T₄** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₉ : **T₃** + Foliar spray of Panchagavya @ 3% at 30 and Vermiwash @ 5 % at 45 DAS

T₁₀: **T₄** + Foliar spray of Panchagavya @ 3% at 30 and Vermiwash @ 5 % at 45 DAS

T₁₁: Sole foxtail millet crop without tree component

RDN: Recommended dose of nitrogen

DAS: Days after sowing

FYM: Farm yard manure

3.4.3.2 Design and layout

The experiment was conducted in Randomized Complete Block Design (RCBD) with three replications. The layout of the experiment was depicted in Fig. 6.

3.4.3.3 Cultural practices

3.4.3.3.1 Land preparation

The land was ploughed by using tractor followed by country plough passing twice. The bigger clods were crushed by passing cultivator and harrowed.

3.4.3.3.2 Plot size, spacing, variety, organic manures application and sowing

After land preparation, experimental plots were laid out as per the plan of layout. Five *Melia dubia* plants spaced at 3 m apart in row of 9 m wide (considering 4.5 m on either side of tree row towards East and West directions) were taken as a unit treatment as gross plot. The gross and net plot sizes for foxtail millet were 135 m² (9 m x 15 m) and 81 m² (9 m x 9 m), respectively. Foxtail millet was sown as an inter crop in *Melia dubia* during *Kharif* season of 2018 and 2019 on 25.08.2018 and 04.07.2019 as per the treatments, respectively. Variety HN-46 seeds were dibbled at 4-5 cm depth in the shallow furrows opened at 30 cm apart with the help of wooden marker. Later seeds were covered manually. Organic manures *viz.*, FYM, vermicompost and poultry manure were applied equivalent to recommended dose of nitrogen *i.e.*, 30 kg N ha⁻¹ by considering their nutrient composition (Annexure III) two weeks before sowing as per the treatments. Liquid organic manures, panchagavya @ 3 % and vermiwash @ 5 % were prepared and sprayed as per the treatments at 30 and 45 days after sowing (DAS). Sole foxtail millet without tree component was cultivated as per the organic package of practices of UAS, Raichur.

3.4.3.4 Aftercare

3.4.3.4.1 Gap filling and thinning

Thinning was done maintaining one healthy seedling per hill after 12 DAS. Gap filling was done at 8 DAS by dibbling seeds to maintain the optimum plant population.

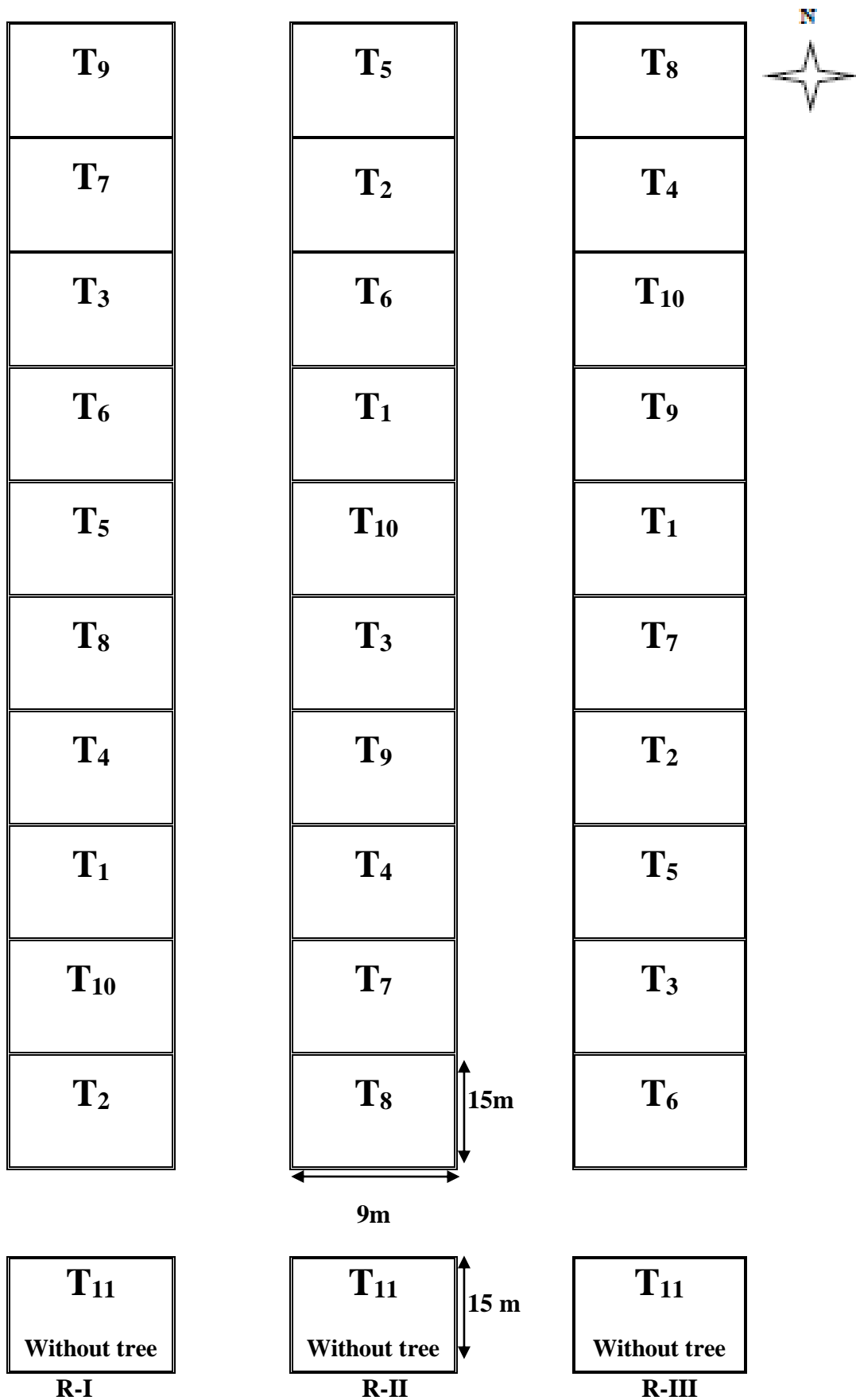


Fig 6. Plan of layout of the experiment - III

3.4.3.4.2 Weed management

Two hand weeding and one hoeing operations at 20 and 30 DAS were carried out during the crop growth to keep the crop weed free condition and there by soil moisture and nutrient losses were reduced.

3.4.3.4.3 Harvesting and threshing

During both the years, crop was harvested after attaining the physiological maturity stage by cutting the plants as close as ground level using sickle on 23.11.2018 (92 DAS) and 06.10.2019 (94 DAS). Later on, harvested plants were sun dried and ear heads were threshed and grain and straw yields per net plot was recorded separately.

3.4.3.4.4 Procedure for preparation of liquid organic manures

Panchagavya: Panchagavya was prepared by using 7 kg fresh cowdung and 1 kg cow ghee mixed thoroughly and stored it for 2 days. These ingredients were mixed thoroughly daily thrice. After 2 days, 3 litres of cow urine and 10 litres of water were added to this solution and were fermented for 15 days with stirring daily twice. Then, 2 litres of milk, 2 litres of curd, 250 g of jaggery, 2 litres of tender coconut water and 12 ripened bananas were added and mixture was allowed to ferment for 15 days with intermittent stirring the contents daily 2 to 3 times. The solution was filtered and used as a spray at the rate of 3 per cent at 30 and 45 DAS.

Vermiwash: Plastic drum with a tap fitted to the bottom placed in the shade. Ten days old dung filled in the drum, allowed for decomposition for 15 days. Then around thousand earthworms were released in the drum. Small drum with the minute hole in the bottom hanged over the drum. After 5 days, extract was collected and used for spray at 30 and 45 DAS at 5 per cent concentration.

3.4.3.5 Collection of experimental data

3.4.3.5.1 Observations on growth and physiological parameters

3.4.3.5.1.1 Plant height (cm)

Plant height of ten randomly selected plants (5 each from East and West direction) was measured in centimeter from base to tip of the plant at 30 and 60 DAS and at harvest.

3.4.3.5.1.2 Number of leaves plant⁻¹

Number of leaves present on each tagged plants were counted at 30 and 60 DAS and at harvest expressed as number of leaves per plant.

3.4.3.5.1.3 No of tillers plant⁻¹

The number of tillers per plant at 60 DAS and at harvest was counted from ten randomly selected plants in which only effective tillers were counted and averaged.

3.4.3.5.1.4 Leaf area per plant (cm²)

Length of fully opened leaves of ten randomly selected plants was measured from the base to the top of the leaf and breadth was taken at the widest point of the leaf lamina. The product of leaf length and the breadth was multiplied by the factor 0.75 (Mungase *et al.*, 1983). Then, the average leaf area was expressed in cm² per plant.

3.4.3.5.1.5 Leaf area index (LAI)

Leaf area index (LAI) was worked out by dividing the total leaf area per plant by land area covered by the plant as per the formulae given by Watson (1952).

$$\text{LAI} = \frac{\text{Leaf area per plant (cm}^2\text{)}}{\text{Land area occupied by the plant (cm}^2\text{)}}$$

3.4.3.5.1.6 Dry matter production and its accumulation in different plant parts

Ten plants (5 each from East and West direction of the tree) were randomly selected and uprooted from destructive rows of each plot at 30 and 60 DAS and at harvest and dried under shade. The samples were separated into leaf, stem and ear head and later on, they were oven dried at 65⁰ C to a constant dry weight was attained. It was recorded separately at each stage for calculating dry matter production and its accumulation in different parts per plant. The mean values for each plant was calculated and expressed in g plant⁻¹.

3.4.3.5.1.7 Absolute growth rate (g plant⁻¹ day⁻¹)

Absolute growth rate (AGR) was worked out by dividing the total dry weight produced between two consecutive sampling dates by the number of days between those

two sampling dates and was expressed as g per plant per day. The following formula was used for the purpose.

$$AGR = \frac{W_2 - W_1}{t_2 - t_1}$$

Where,

W_1 - Dry matter of plant in “g” at time t_1

W_2 - Dry matter of plant in “g” at time t_2

t_1 and t_2 are two consecutive sampling dates

3.4.3.5.1.8 Crop growth rate ($g\ m^{-2}day^{-1}$)

Crop growth rate (CGR) was calculated by using the formula suggested by Peng *et al.* (1993). It was estimated at 30 and 60 DAS and at harvest stages and expressed in $g\ m^{-2}\ day^{-1}$.

$$CGR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{1}{P}$$

Where,

W_1 and W_2 - Whole plant dry weight at time t_1 and t_2 respectively, P - Ground area occupied by the plant (m^2), and t_1 and t_2 - Time interval in days.

3.4.3.5.1.9 Relative growth rate ($g\ g^{-1}\ day^{-1}$)

Relative growth rate (RGR) is the rate of increase in dry weight per unit time and was calculated by using the formula suggested by Radford (1967). It was estimated between 30 and 60 and at harvest stages and expressed in $g\ g^{-1}\ day^{-1}$.

$$RGR = \frac{\text{Log}_e W_2 - \text{Log}_e W_1}{t_2 - t_1}$$

Where,

W_1 and W_2 - Whole plant dry weight at time t_1 and t_2 respectively, and t_1 and t_2 - Time interval in days.

3.4.3.5.2 Observations on yield and yield parameters

Observations on yield parameters were collected from ten randomly selected plants (Five each from East and West direction of the tree) at harvest from the each net plot area of each treatment.

3.4.3.5.2.1 Length of ear head (cm)

Ear head length was measured from base to the tip of ear head and expressed in centimeter (cm).

3.4.3.5.2.2 Weight of ear head (g)

The mean of ear head weight worked out by taking the oven dry weight of ten randomly selected plants and average weight was worked out and expressed in gram as weight of ear head.

3.4.3.5.2.3 Grain weight (g plant⁻¹)

The dried ear heads were threshed and the mean weight of the grain of ten ear heads were taken as the grain weight per ear head and expressed in g plant⁻¹.

3.4.3.5.2.4 Test weight (g)

1000 grains weight was recorded from the grain samples drawn from each net plot area and expressed in 'g'.

3.4.3.5.2.5 Grain yield (kg ha⁻¹)

At physiological maturity, plants from each net plot were harvested and ear heads were separated, air dried, threshed, cleaned and weighed. Grain yield per hectare was worked out and expressed in kg ha⁻¹.

3.4.3.5.2.6 Straw yield (kg ha⁻¹)

Straw yield from net plot area recorded after sun drying for 8-10 days after harvesting. The straw yield of foxtail millet was recorded after complete sun drying of stalks from each net plot and expressed in kg ha⁻¹.

3.4.3.5.2.7 Harvest index (HI)

Harvest index was estimated as per the formula suggested by Donald (1962).

$$HI = \frac{\text{Economic yield (kg ha}^{-1}\text{)}}{\text{Biological yield (kg ha}^{-1}\text{)}} \times 100$$

3.4.3.5.3 Soil analysis

3.4.3.5.3.1 Collection of soil samples

Soil samples (0-30 cm depth) were collected from each of the thirty three plots of the experimental field during both years by adopting the quadrant technique after the harvest of the foxtail millet crop. The samples were dried in shade, grounded with wooden mallet, passed through a 2 mm sieve and stored in polythene bags for analysis of nutrients.

3.4.3.5.3.2 Methodology for soil analysis

The soil samples collected after the harvest of foxtail millet were analyzed for physical, chemical and biological properties of soil by employing standard methods of analysis.

3.4.3.5.3.2.1 Particle size analysis

Particle size distribution in soil samples was determined by international pipette method as described by Piper (1966) using sodium hydroxide as a dispersing agent. From the dispersed suspension an aliquot of clay + silt and clay were pipetted out from specified depth at their specific time intervals depending on the suspension temperature. The total sand obtained by repeated decantation of silt and clay.

3.4.3.5.3.2.2 Chemical properties

3.4.3.4.3.2.2.1 pH and electrical conductivity (dSm⁻¹)

The soil pH was determined in 1:2.5 soil: water suspension using digital pH meter with glass electrode (Jackson, 1973). The electrical conductivity of soil was determined using clear extract of soil: water suspension using conductivity bridge (Jackson, 1973).

3.4.3.5.3.2.2.2 Organic carbon (%)

The dry soil samples were powdered using pestle and mortar and passed through 0.2 mm sieve. A known weight of finely powdered sample was treated with excess but known volume of standard $K_2Cr_2O_7$ and concentrated H_2SO_4 . The unused $K_2Cr_2O_7$ was quantified by back titration with standard ferrous ammonium sulphate (FAS) using diphenyl amine as an indicator (Jackson, 1973).

3.4.3.5.3.2.2.3 Available nitrogen ($kg\ ha^{-1}$)

The available nitrogen was determined by alkaline potassium permanganate method (Hesse, 1971). A known weight of soil was treated with excess amount of potassium permanganate with 25 per cent NaOH solution. The liberated ammonia was trapped in boric acid mixed indicator solution and determined by titration against standard H_2SO_4 . The available nitrogen content of the soil was calculated by following formula.

$$\text{Available N} = \frac{\text{TV} \times \text{N of } H_2SO_4 \times 0.014 \times 10^9 \times 2.24}{\text{Weight of soil sample (g)}}$$

3.4.3.5.3.2.2.4 Available phosphorus ($kg\ ha^{-1}$)

Available phosphorus in soil was extracted by Olsen's extractant 0.5 M $NaHCO_3$ and phosphorus was determined by stannous chloride molybdophosphoric blue colour method (Hesse, 1971). The blue color was developed by chloromolybdic acid and intensity of blue colour was determined at 660 nm. The available phosphorus content of the soil was calculated by following formula.

$$\text{Available } P_2O_5 = \frac{\text{Graph ppm} \times \text{Vol. of extract} \times \text{Volume made} \times 2.24 \times 2.29 \times 10^9}{P_2O_5 (kg\ ha^{-1}) 10^6 \times \text{Aliquot taken} \times \text{Weight of soil sample}}$$

3.4.3.5.3.2.2.5 Available potassium ($kg\ ha^{-1}$)

Available potassium was extracted with neutral normal ammonium acetate solution and was determined using flame photometer as described by Jackson (1973). The available potassium content of the soil was calculated by following formula.

$$\text{Available } K_2O (kg\ ha^{-1}) = \frac{\text{PPM} \times \text{Volume of extract} \times \text{Volume made} \times 1.20 \times 2.24 \times 10^9}{10^6 \times \text{Weight of soil sample} \times \text{Aliquot taken}}$$

3.4.3.5.3.2.3 Soil biological properties

The soil samples were collected from the rhizosphere of the plants before sowing of crop, at 60 DAS and harvest during 2018 and 2019 from all the treatments and these soils were placed in a polyethylene bag and brought to laboratory and stored in refrigerator at 5° C until used for analysis.

3.4.3.7.3.2.3.1 Microbial population

The rhizosphere soil samples collected from experimental site were analyzed for different soil microorganisms (Bacteria, Fungi and Actinomycetes) by serial dilution and plating techniques using specific media (Table 1).

3.4.3.5.3.2.3.2 Enzyme activities

The alkaline phosphatase and dehydrogenase activities in soil were determined by the method given by Evazi and Tabatabai (1979).

The alkaline phosphatase activities was analysed by quantifying the amount of p- nitrophenol released (PNR) and expressed as $\mu\text{g PNR cfu g}^{-1} \text{ soil hr}^{-1}$.

Dehydrogenase assays based on the 2,3,5-triphenyl tetrazolium chloride to the creaming red coloured triphenol formazan (TPF) and it was quantifying the amount of TPF released and expressed as of $\mu\text{g TPF produced g}^{-1} \text{ soil day}^{-1}$.

3.4.3.5.4 Analysis of plant sample

In experiment III, plant samples collected at harvest weres grounded in Willey mill to pass through 40 mm mesh sieve. The ground material was collected in butter paper bags and later used for chemical analysis. Nitrogen, phosphorus and potassium were estimated by following standard procedures given by Jackson (1973). Based on nutrient content of plants and dry matter production, uptake of nitrogen, phosphorus and potassium were worked out.

Nutrient uptake for N, P and K was calculated by the formulas as mentioned below.

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

3.4.3.5.5 Tree observations

At the beginning of the experiment and at harvest of crop during 2018 and 2019, following observations were recorded.

3.4.3.5.5.1 Tree height (m)

The height of three *Melia dubia* trees in each plot was measured using a measuring tape fixed on a straight wooden stick from the ground level to the tip of the main branch, which was expressed in metre (m).

3.4.3.5.5.2 Bole height (m)

The bole height of three trees in each plot was measured using a measuring tape fixed on a straight wooden stick from the ground level to the crown point, which was expressed in metre (m).

3.4.3.5.5.3 Girth at breast height- GBH (cm)

The girth at breast height was recorded by using wooden caliper at 1.37 m above the base of the plant and it was expressed centimeter (cm).

3.4.3.5.5.4 Diameter at breast height – DBH (cm)

The diameter at breast height was measured with measuring tape at 1.37 m above the base of the plant and it was expressed in centimeter (cm).

3.4.3.5.5.5 Collar diameter (cm)

Collar diameter of the tree was measured at base of the tree and expressed in centimeter (cm).

3.4.3.5.5.6 Canopy spread (m)

Canopy spread was determined at east-west and north-south directions using measuring tape and expressed in meter (m).

3.4.3.5.5.7 Light interception (%)

Light interception was recorded using lux meter in both the years at 75 DAS and light reduction was computed using the following formulae

$$\text{Light reduction (\%)} = \frac{\text{Light intensity outside canopy} - \text{Light intensity under canopy}}{\text{Light intensity outside canopy}} \times 100$$

3.4.3.5.5.8 Total wood volume (m³)

The following formulae was used for calculating the standing volume of trees

$$\text{Volume (m}^3\text{)} = \pi \times (D/2)^2 \times H$$

Where,

D is the diameter at breast height (DBH in m) H is the bole height of the tree (m).

3.4.3.5.5.9 Tree biomass (t ha⁻¹)

Non-destructive method of biomass estimation was carried out using volume (tree bole height, DBH) and wood density. Wood density of 6 years old *Melia dubia* tree is 500.2 kg m⁻³ (Saravanan *et al.*, 2014)

3.4.3.5.5.9.1 Above ground biomass (AGB) (t ha⁻¹)

The following formula was used for calculating the standing above ground biomass

$$\text{Above ground biomass} = \text{Volume (m}^3\text{)} \times \text{Wood density (kg m}^{-3}\text{)}.$$

Then biomass was converted into t ha⁻¹.

3.4.3.5.5.9.2 Below ground biomass (BGB) (t ha⁻¹)

Below ground biomass of the tree was calculated using 0.26 factor of root: shoot ratio (Gupta and Sharma, 2014)

$$\text{BGB (kg tree}^{-1}\text{)} = \text{AGB (kg tree}^{-1}\text{)} \times 0.26$$

Then biomass was converted into t ha⁻¹.

3.4.3.5.5.9.3 Total tree biomass (t ha⁻¹)

Sum of above ground and below ground biomass gave total biomass (TB) of the tree (Pandya *et al.*, 2014)

$$\text{TB (kg tree}^{-1}\text{)} = \text{AGB (kg tree}^{-1}\text{)} + \text{BGB (kg tree}^{-1}\text{)}.$$

Then biomass was converted into t ha⁻¹.

3.4.3.5.5.10 Carbon stocks and sequestration

3.4.3.5.5.10.1 Carbon stocks (t ha⁻¹)

Both above and below ground biomass was converted into above and below ground carbon stocks with following formula (Suryawanshi *et al.*, 2014).

$$\text{Carbon stocks (t ha}^{-1}\text{)} = 0.50 \times \text{TB (t ha}^{-1}\text{)}$$

The total carbon storage was calculated by adding carbon stocks in above and below ground biomass.

3.4.3.5.5.10.2 Carbon sequestration (t ha⁻¹)

The CO₂ equivalents (quantity of C x 44/12) were arrived from carbon stocks for calculating CO₂ sequestration (t ha⁻¹) by biomass of *Melia dubia* trees in agroforestry system (Nguyen *et al.*, 2012).

$$\text{Carbon sequestration (t ha}^{-1}\text{)} = \text{C stock} \times 44/12$$

3.4.3.6 Economic analysis

Economic analysis of foxtail millet cultivation with tree and without tree component and system analysis was calculated. For system economic analysis, tree wood volume was used for calculation of gross return, net returns and benefit cost ratio.

3.4.3.6.1 Cost of cultivation (Rs. ha⁻¹)

The price of inputs that were prevailing at the time of their use was considered to work out the cost of cultivation. In agroforestry system, cost of cultivation of *Melia dubia*

since its establishment was considered. The details considered to work out the economics are given in Appendix-II and III.

3.4.3.6.2 Gross returns (Rs. ha⁻¹)

The price of the crop products prevailing in the market after the harvest was obtained from the Agriculture Produce Market Committee (APMC) and was used for the calculation of gross returns. For wood market price, Rs 125 per cubic foot was considered.

3.4.3.6.3 Net returns (Rs. ha⁻¹)

The net returns per hectare were calculated by deducting the cost of cultivation from the gross returns.

3.4.3.6.4 Benefit cost ratio (B: C)

Benefit Cost ratio was worked out by using the following formula,

$$\text{Benefit: cost} = \frac{\text{Gross returns (Rs. ha}^{-1}\text{)}}{\text{Cost of cultivation (Rs. ha}^{-1}\text{)}}$$

3.4.4 Experiment-IV: Early growth performance of *Melia dubia* under high density planting system

The experiment was conducted at Biofuel Park, ARS, Tinthani. The treatments comprising of seven levels of spacing for *Melia dubia* species.

3.4.4.1 Treatment details

T₁: 2 m x 1 m (5000 trees ha⁻¹)

T₂: 2 m x 2 m (2500 trees ha⁻¹)

T₃: 3 m x 1 m (3333 trees ha⁻¹)

T₄: 3 m x 2 m (1667 trees ha⁻¹)

T₅: 4 m x 1 m (2500 trees ha⁻¹)

T₆: 4 m x 2 m (1200 trees ha⁻¹)

T₇: 9 m x 3 m (370 trees ha⁻¹)

3.4.4.2 Design and Layout

Experiment was laid out on Randomized Complete Block Design (RCBD) with three replications. Layout of the experiment was given in Fig. 7. Six plants in each treatment were considered for the study.

3.4.4.3 Plot size and spacing

Spacing	Gross plot size (m ²)	Net plot size (m ²)
T ₁ : 2 m x 1 m	36	16
T ₂ : 2 m x 2 m	72	32
T ₃ : 3 m x 1 m	54	24
T ₄ : 3 m x 2 m	108	48
T ₅ : 4 m x 1 m	72	32
T ₆ : 4 m x 2 m	144	64
T ₇ : 9 m x 3 m	27	27

3.4.4.4 Cultural practices

3.4.4.4.1 Pits digging and filling with materials

After thorough land preparation pits were dug with a size of 60 x 60 x 60 cm³. Pits were filled with equal proportion of FYM and sand.

3.4.4.4.2 Planting

Six months old uniform *Melia dubia* seedlings were brought from Forest nursery and planted in pits as per the treatments on 07.07.2018.

3.4.4.4.3 Manuring, irrigation and weeding

Manuring was made in the form of known quantity of FYM twice in a year for maintenance. Protective irrigation was given whenever moisture required. At three months' interval weeding was done.

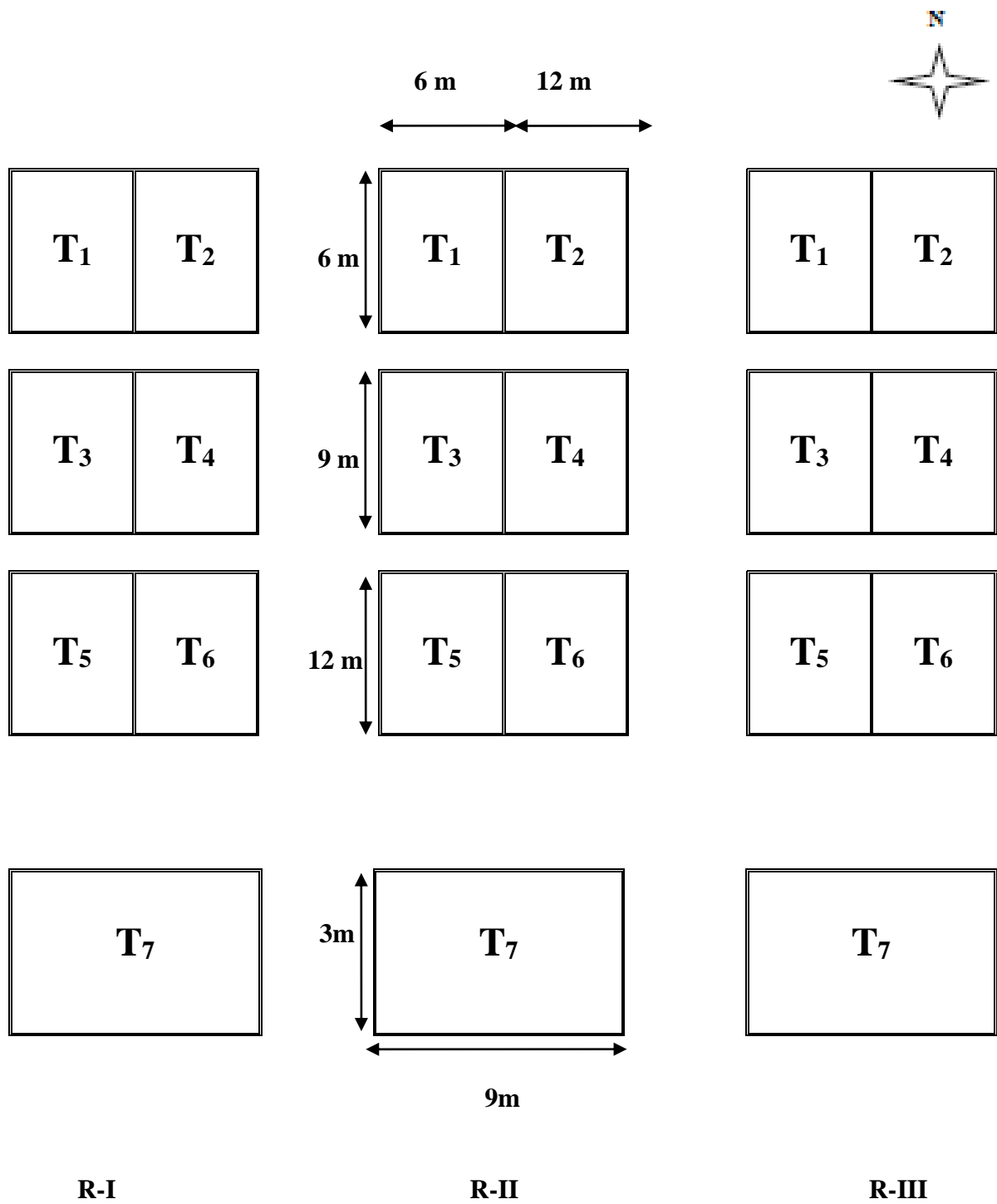


Fig 7: Plan of layout of the Experiment – IV

3.4.4.4 Collection of data

3.4.4.4.1 Tree observations

Observations on tree growth parameters were recorded from three plants in net plot area at three months' interval.

3.4.4.4.1.1 Tree height (m)

The height of three trees in each plot was measured using leveler staff from the ground level to the tip of the main branch, which was expressed in metre.

3.4.4.4.1.2 Bole height (m)

The bole height of three trees in each plot was measured using leveler staff from the ground level to crown point, which was expressed in metre (m).

3.4.4.4.1.3 Girth at breast height- GBH (cm)

The girth at breast height was recorded by using wooden caliper at 1.37 m above the base of the plant and it was expressed in centimeter (cm).

3.4.4.4.1.4 Diameter at breast height – DBH (cm)

The diameter at breast height was measured with measuring tape at 1.37 m above the base of the plant and it was expressed in centimeter (cm).

3.4.4.4.1.5 Collar diameter (cm)

Collar diameter was measured by recording diameter at the base of the tree and expressed in centimeter (cm).

3.4.4.4.1.6 Canopy spread (m)

Canopy spread was determined at east-west and north-south directions using measuring tape and expressed in meter (m).

3.4.4.4.1.7 Light interception (%)

Light interception was recorded using lux meter and light reduction was computed using the following formula,

$$\text{Light reduction (\%)} = \frac{\text{Light intensity outside canopy} - \text{Light intensity under canopy}}{\text{Light intensity outside canopy}} \times 100$$

3.5 Statistical analysis

The observations recorded in these studies were analyzed statistically for test of significance following the Fisher's method of analysis of variance (ANOVA) as outlined by Cochran and Cox (1967). The level of significance on 'F' test was tested at 5 per cent for experiment III and IV and 1 per cent for experiment II. The results have been discussed based on critical difference at $P = 0.05$ and 0.01 . Wherever the treatment differences were found non-significant, it was denoted as 'NS'.

RESULTS AND DISCUSSION

IV. RESULTS AND DISCUSSION

The results of the investigation on “Agronomic manipulations for productivity and income enhancement in *Melia dubia* Cav. based agroforestry system under organic production” conducted during 2018 and 2019 at University of Agricultural Sciences, Raichur is presented in this chapter. The results of the investigation have also been discussed in detail along with causes of variation among the different treatments. Following studies were conducted during investigations.

1. Survey on performance of *Melia dubia* in agroforestry system on farmers’ field in Kalyana Karnataka region
2. Effect of pre-sowing seed treatment on germination of *Melia dubia*
3. Performance of foxtail millet as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system
4. Early growth performance of *Melia dubia* under high density planting system

For easier expression of the outcomes, the results and discussion chapter is divided into following sub headings.

4.1 Effect of weather on crop performance (cf. Table 2 & 3 and Fig. 1 to 4)

The experiment on “Performance of foxtail millet as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system” was conducted on farmer field at Santhekellur village in Lingsugur taluka of Raichur district, while the other two experiments viz., “Effect of pre-sowing seed treatment on germination of *Melia dubia*” and “Early growth performance of *Melia dubia* under high density planting system” were laid out at Biofuel Park, ARS, Tinthani, which is located at North Eastern part of Karnataka (Zone 2) of UAS, Raichur jurisdiction. From the weather data, it was observed that the average annual rainfall at Santhekellur village for the past 29 years was 557.5 mm (Table 2). The rainfall during 2018 and 2019 was 404.0 mm and 541.0 mm which was 37.99 and 6.38 per cent less than the normal rainfall. The rainfall during 2019 was 33.91 per cent higher than that during 2018 which had marked greater effect on growth and yield of foxtail millet and *Melia dubia* species. Further it also had influence on quick mineralization of applied and native nutrients through organic manures. Owing

to deficit of rainfall during cropping period of first year, two critical irrigations were given. Relative humidity had no significant effect on pest and diseases of foxtail millet. The average maximum monthly temperature varied from 29.38 (December) to 39.03⁰C (May) and 27.26 (December) to 39.45 ⁰C (May) during 2018 and 2019, respectively. While, mean minimum temperature ranged from 16.25 (January) to 26.2 ⁰C (May) and 14.23 (January) to 26.16 ⁰C (May) during 2018 and 2019, respectively. April and May months were hottest months.

Weather data at Biofuel Park, ARS, Tinthani (RSK, Kakkera) revealed that the average annual rainfall for the past 29 years was 520.51 mm (Table 3). The amount of rainfall received during 2018 and 2019 was 357.50 and 513.0 mm, respectively. The rainfall during 2019 was 43.50 per cent higher than that during 2018. This situation resulted in positive effect on growth of *Melia dubia* tree. Mean monthly maximum temperature varied from 29.38 (December) to 39.03 ⁰C (May) and 30.43 (December) to 41.96 ⁰C (May) during 2018 and 2019, respectively, while, minimum temperature ranged from 15.96 (January) to 26.38 ⁰C (May) and 19.83 (January) to 27.62 ⁰C (May) during 2018 and 2019, respectively. The prevailing weather during experimentation period of both the years favoured for better growth of foxtail millet and *Melia dubia* tree.

5. Experiment - I: Survey on performance of *Melia dubia* in agroforestry system on farmer's field in Kalyana Karnataka region

4.2.1 Categorization of general information about cultivation of *Melia dubia* in Kalyana Karnataka region (cf. Table 4)

Forests provide society with benefits like wood products, annual products and environmental protection, catchment protection, nature conservation, climatic amelioration etc. Due to increased population, there is heavy pressure on the needs of the society. The majority of the agricultural families maintain large herds of cattle, sheep and goats because their income is augmented marginally by the production of cattle population and also cattle dung manure. Most of their cattle, sheep and goats depend on forest. Even today people staying in forest fringe villages have the practice of using fuel wood for cooking and other purposes. Apart from these requirements, people have to depend upon the forests for agricultural implements, fencing, handicrafts and building materials. As a consequence of practicing age old agriculture cropping pattern, forests

have to bear the brunt of an ever increasing demand for wood, fuel wood and grazing which cause great damage to the existing forests. Hence, agroforestry can be adopted to meet the requirements of people and species like *Melia dubia* is being promoted which is fast growing and can fulfill their needs such as timber, fuel wood and also fodder, thereby farmers become self-reliant and economically stable. Apart from these benefits, the cultivation of *Melia dubia* increases the organic matter content of soil due to accumulation of litter which in turn enhances soil fertility. In recent years, farmers in Kalyana Karnataka region are growing *Melia dubia* in their farm lands to fulfill their livelihood needs and contributing to increasing the green cover. Still many farmers are reluctant towards adoption of agroforestry system. Hence, a survey was conducted in Kalyana Karnataka region and data were collected from 38 farmers in six districts with an objective to investigate performance of *Melia dubia* on farmers' field. In general, the management of *Melia dubia* plantation during later years (from second or third year onwards) with most of the farmers rested with organic eco-system.

4.2.1.1 Distribution of farmers according to adoption of *Melia dubia* (cf. Table 4)

Data were collected from 38 farmers who adopted *Melia dubia* in 67.48 ha. Out of 38 farmers, 24 respondents were farmers whose livelihood depends only on farming which covered 35.28 ha. It means that more than 60 per cent respondents were farmers followed by 28.95 per cent businessmen. These businessmen adopted *Melia dubia* with purpose of getting higher income only.

4.2.1.2 Distribution of respondents according to age of *Melia dubia* species (cf. Table 4)

Melia dubia tree was recently introduced in Kalyana Karnataka region, only some people have known about the tree. Out of 38, 13 respondents planted *Melia dubia* in last two years which was major part of respondent. Out of total area adopted, 21.00 ha area was under *Melia dubia* plantation in last two years. Less than 3.0 per cent farmers adopted *Melia dubia* in 8 years back.

4.2.1.3 Distribution of respondents according to type of soil in which *Melia dubia* was adopted (cf. Table 4)

About 84.21 per cent respondents cultivated *Melia dubia* in red soils under irrigated condition, which covered 88.74 per cent of total area. It indicated that farmers who were having irrigation facilities have adopted *Melia dubia* in their field.

4.2.1.4 Distribution of respondents according to type of ecosystem in which *Melia dubia* was adopted (cf. Table 4)

Looking into the importance of *Melia dubia* through wider publicity and farmers who have irrigation facilities started adopting *Melia dubia* in their field. In present study also, out of 38, 32 respondents adopted *Melia dubia* under irrigated condition which covered 88.74 per cent of total area.

4.2.1.5 Distribution of respondents according to type of *Melia dubia* based agroforestry system adopted (cf. Table 4)

About 63.16 per cent farmers adopted intercrops in *Melia dubia* based agroforestry system which covered 66.39 per cent of total area. Ten respondents cultivated *Melia dubia* as sole crop, which covered 23.53 per cent of total area.

4.2.1.6 Distribution of respondents according to type of intercrops adopted in *Melia dubia* based agroforestry system (cf. Table 4)

With respect to adoption of intercrops in *Melia dubia*, 63.16 per cent respondents adopted intercrops in between definite row proportion of *Melia dubia*, while, 26.31 per cent respondents cultivated as sole plantation and 10.53 per cent farmers had *Melia dubia* as hedge plantation. In inter cropping adoption, 16 respondents adopted horticultural plantation crops like pomegranate, papaya and lime which covered 42.10 per cent of total area while 5.26 percentage of respondents adopted intercropping with field crops due to very poor awarness about the concept.

4.2.1.7 Distribution of respondents according to plant density of *Melia dubia* adopted (cf. Table 4)

Regarding *Melia dubia* plant density, 44.74 per cent respondents had 501 to 1000 trees ha⁻¹, which covered 52.16 per cent of total area followed by 28.95 per cent respondents with 73 to 500 trees ha⁻¹. Only two respondents adopted higher plant density (2001 to 2500 trees ha⁻¹), which covered 5.93 per cent of total area.

From the studies, it was observed that many of the plantations were of different types of planting systems identified as monocultures (very few), mixed block plantations, bund planting, etc. In case of small land holdings, majority of the farmers practiced border planting. The spacing followed varied with individual land holding, type of intercropping, availability of water and requirement of the farmer. Generally, while establishing plantations, six months old seedlings were planted in pits (0.216 m³). The average spacing adopted for an inter crop was 3.3 m x 3.3 m, 4.0 m x 3.3 m and under hedge planting, wider spacing from 9 m to 30 m to 3 m to 4.5 m. Most of the farmers expressed that a pit size of 60 cm x 60 cm x 60 cm (0.216 m³) with a spacing of 3.3 m x 3.3 m is ideal for attaining better growth within a short period.

Most of farmers are using sarees for protecting fruits under high temperature to avoid sunburn, which is common practice in the region that cost around Rs 1.00 lakh ha⁻¹. To avoid such problem, farmers have adopted *Melia dubia* plantation as an inter crops in pomegranate, papaya and lime. These opinions are in conformity with the findings of Kulkarni (2017) who conducted participatory research to know the performance of *Melia dubia* in agroforestry system and reported that *Melia dubia* showed positive effect on quality of pomegranate fruits by reducing scorching effect through sunlight. Incidence of bacterial blight was also not noticed in new plantations but anthracnose (2 to 7%) was noticed in few gardens.

4.2.2 Distribution of farmers according to their opinion on source of information for adoption of *Melia dubia* based agroforestry system (cf. Table 5 and Fig. 8)

The data regarding source of information for adoption of *Melia dubia* was divided into six categories. Data was collected from 38 respondents but multiple answers were given by the adopters. Totally 106 answers were given by 38 respondents. Most of respondents gathered information from TV/You Tube and fellow farmers, which covered

Table 4. Categorization of general information about cultivation of *Melia dubia* in Kalyana Karnataka region

n=38

I. Distribution of respondents according to adoption of <i>Melia dubia</i> based agroforestry system				
Category	No. of respondents	Percentage	Area (ha)	Percentage
Farmers	24	63.16	35.28	52.28
Businessmen	11	28.95	27.80	41.19
Employ	03	07.89	04.40	06.52
Total	38	100.00	67.48	100.00
II. Distribution of respondents according to the age of <i>Melia dubia</i> species on their fields				
Category	No. of respondents	Percentage	Area (ha)	Percentage
2 years	13	34.21	21.00	31.12
3 years	08	21.05	17.08	25.32
4 years	06	15.79	8.00	11.85
5 years	05	13.16	9.80	14.52
6 years	05	13.16	9.20	13.63
8 years	01	02.63	2.40	03.56
Total	38	100.0	67.48	100.00
III. Distribution of respondents according to type of soil in which <i>Melia dubia</i> was adopted				
Category	No. of respondents	Percentage	Area (ha)	Percentage
Black soil	06	15.79	07.60	11.26
Red soil	32	84.21	59.88	88.74
Total	38	100.00	67.48	100.00
IV. Distribution of respondents according to type of ecosystem in which <i>Melia dubia</i> is adopted with corresponding area				
Category	No. of respondents	Percentage	Area (ha)	Percentage
Rainfed	06	15.79	07.60	11.26
Irrigated	32	84.21	59.88	88.74
Total	38	100.00	67.48	100.00
V. Distribution of respondents according to type of <i>Melia dubia</i> based agroforestry system adopted with the corresponding area				
Category	No. of respondents	Percentage	Area (ha)	Percentage
Sole	10	26.31	15.88	23.53
Hedge	04	10.53	06.80	10.08
Intercropping	24	63.16	44.80	66.39
Total	38	100.00	67.48	100.00
VI. Distribution of respondents according to type of intercrops adopted in <i>Melia dubia</i> based agroforestry system with the corresponding area				
Type of intercrops	No. of respondents	Percentage	Area (ha)	Percentage
Without intercrops	10	26.31	15.88	23.53
Field crops	02	5.26	07.40	10.97
Vegetable and Flower crops	05	13.16	06.20	9.19
Horticulture plantation	16	42.11	31.40	46.53
Trees (Sandalwood tree)	05	13.16	06.60	9.78
Total	38	100.00	67.48	100.00
VII. Distribution of respondents according to plant density of <i>Melia dubia</i> adopted				
No of plants ha⁻¹	No. of respondents	Percentage	Area (ha)	Percentage
73-500	11	28.95	16.28	24.13
501-1000	17	44.74	35.6	52.76
1001-1500	05	13.16	06.00	08.89
1501-2000	03	07.89	05.60	08.30
2001-2500	02	05.26	04.00	05.93
Total	38	100.00	67.48	100.00

63.15 per cent each. This is mainly attributed to availability of smart phones in the villages. The common phenomenon in the villages is that if a progressive farmer adopts recent technologies that will be replicated by neighbouring farmers which is the best media for dissemination of developed technologies.

4.2.3 Distribution of respondents according to their opinion based on knowledge they had gained for adoption of *Melia dubia* (cf. Table 6)

Data regarding purpose of adoption on performance of *Melia dubia* on farmer's field was collected from 38 respondents. Majority of farmers (54.21 %) expressed that they did not know about role of *Melia dubia* in control of pest and diseases, 39.47 per cent respondents opined that there was increase in yield of crops at early stage of tree plantation and 28.95 per cent each respondent gave feedback on shade effect, poor germination of crop near vicinity and reduction in yield of intercrops due to *Melia dubia* plantation at later stage of establishment (After 5-6 years).

4.2.4 Distribution of respondents according to their opinion on objectives of *Melia dubia* plantation (cf. Table 7 and Fig. 9)

Data regarding feedback on performance of *Melia dubia* collected from 38 respondents was categorized into nine different classes. The 63.53 per cent of respondents adopted *Melia dubia* to serve as a wind breaker in horticulture plantations, followed by 44.74 per cent of respondents for improvement of soil fertility, 31.58 per cent of respondents to create shade in pomegranate, papaya and lime and 28.95 per cent of respondents for timber purpose.

Melia dubia semi deciduous tree sheds dense foliage and abundant fruits and adds enormous quantity of organic matter to the soil which enhances the microbial activity and also enhances soil fertility thereby increasing yields of agricultural crops. It is most suitable for afforestation programmes as it has the capacity to survive at an elevation ranging from 100 m to 2000 m above MSL. It was reported that *Melia dubia* along with *Trichoderma viridae* was able to degrade commonly occurring pesticide in soil residues and hence can be recommended for soil reclamation (Nuthan *et al.*, 2009).

4.2.5 Distribution of non-adopted farmers according to their opinion on non-adoption of *Melia dubia* plantation (cf. Table 8)

Data were collected from 38 non adopted farmers next to farmer's fields who cultivated *Melia dubia*. Totally nine questions were formulated and distributed to respondents according to their response. The data given in Table-8 indicated that that all respondents expressed that they were not willing to grow *Melia dubia* due to market problem. Other problems were long gestation period as responded by 81.58 per cent and 61.58 per cent due to lack of awareness about cultivation of *Melia dubia*, 55.26 per cent due to their small size land holding and 47.37 per cent due to non availability of quality seedlings at affordable price. This emphasized that most of farmers did not have information on *Melia dubia* cultivation and its marketing. Many research studies have proved that when the crops were grown under monocultural system, the soil resources could not be utilized in their full extent. While by making a combination of agricultural crops with trees, the farmers can get better soil fertility and economic returns (Nair, 1996). According to HESS's (Household Energy Strategy Study) demand survey, the main reasons for farmers not to plant trees were lack of water (35 %), not having enough land (13 %), bad effect on crops (12 %) and lack of interest in planting trees (15 %). This highlights that farmers must be informed about advantages or benefits of leguminous and non leguminous tree species and their main effect on soil fertility through tree planting campaigns, trainings and workshops. *Melia* species would fetch best market value in irrigated areas. Primary and secondary marketing points near to villages need to establish to facilitate the farmers who want to promote agroforestry.

4.2.6 Growth parameters

Studies on growth parameters of *Melia dubia* were made on farmers' fields under both pure plantations and agroforestry systems. Growth parameters such as tree height (m), bole height (m), girth and collar diameter were recorded in all six aged group trees viz., a) 2 years, b) 3 years, c) 4 years, d) 5 years, e) 6 years and f) 8 years both under irrigated (red soils) and rainfed (black soils) situations and the economic yield was estimated as volume per plant ($\text{m}^3 \text{ plant}^{-1}$) by using below formula.

$$\text{Volume} = \pi \times \text{Collar diameter} \times \text{Tree height}$$

Where as $\pi = 22/7$

Table 5. Distribution of farmers according to their opinion on source of information for adoption of *Melia dubia* based agroforestry system n=38

Sl.No	Source of information	Frequency	Per cent	Rank
1	TV/You Tube	24	63.15	I
2	News paper/Magazine	19	50.00	II
3	Fellow farmer	24	63.15	I
4	Forest dept	18	47.30	III
5	Scientists	17	44.70	IV
6	Krishimela	4	10.50	V

Table 6. Distribution of respondents according to their opinion based on knowledge they gained for adoption of *Melia dubia* n=38

Sl.No	Purpose for adoption	Frequency	Per cent	Rank
1	Greenary	3	7.89	VII
2	Field boundary	8	21.02	VI
3	Erosion control	1	2.63	IX
4	Timber purpose	11	28.95	IV
5	Fuel wood	2	5.26	VIII
6	Shade	12	31.58	III
7	Wind breaker	23	60.53	I
8	Soil fertility improvement	17	44.74	II
9	Control of pest and disease	9	23.68	V

Table 7. Distribution of respondents according to their opinion on objectives of *Melia dubia* plantation n=38

Sl.No	Purpose of adoption	Frequency	Per cent	Rank
1	Shade effect	11	28.95	III
2	Poor germination of crops near vicinity	11	28.95	III
3	Moisture depletion	0	00.00	V
4	Difficulty in agril operation due to rooting	0	00.00	V
5	Yield reduction	11	28.95	III
6	Increase in yield of inter crops	15	39.47	II
7	Increase in pest and diseases	0	00.00	V
8	Decrease in pest and diseases	6	15.79	IV
9	Don't know about pest and diseases control	32	54.21	I

Table 8. Distribution of non-adopted farmers according to their opinion on non-adoption of *Melia dubia* plantation n=38

Sl.No	Reason for non adoption	Frequency	Per cent	Rank
1	Lack of awareness	23	60.53	III
2	Lack of extension service	1	2.63	VIII
3	Small size holding	21	55.26	IV
4	Non availability of seedlings	18	47.37	V
5	Hindering farm operation	0	0.00	IX
6	Shade effect to neighbouring field	12	31.58	VI
7	Reduces crop yield	4	10.53	VII
8	Long gestation period	31	81.58	II
9	Market problem	38	100.00	I

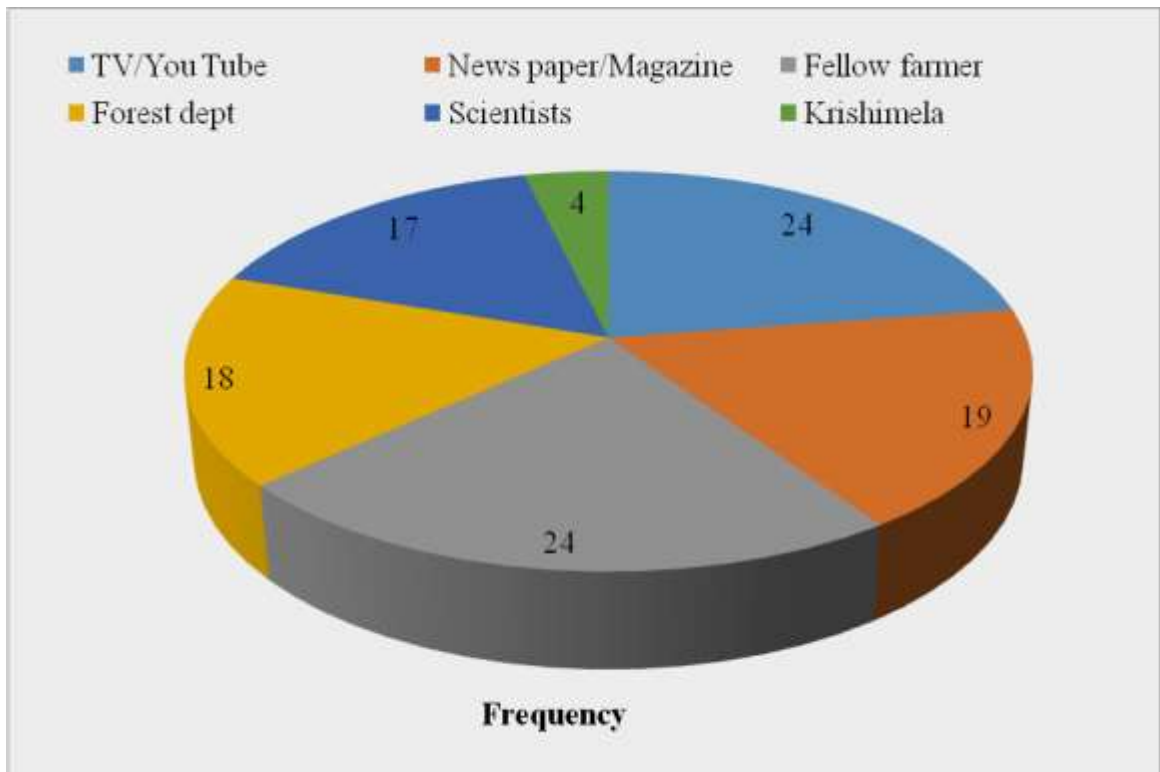


Fig. 8. Distribution of farmers according to their opinion on source of information for adoption of *Melia dubia* based agroforestry system

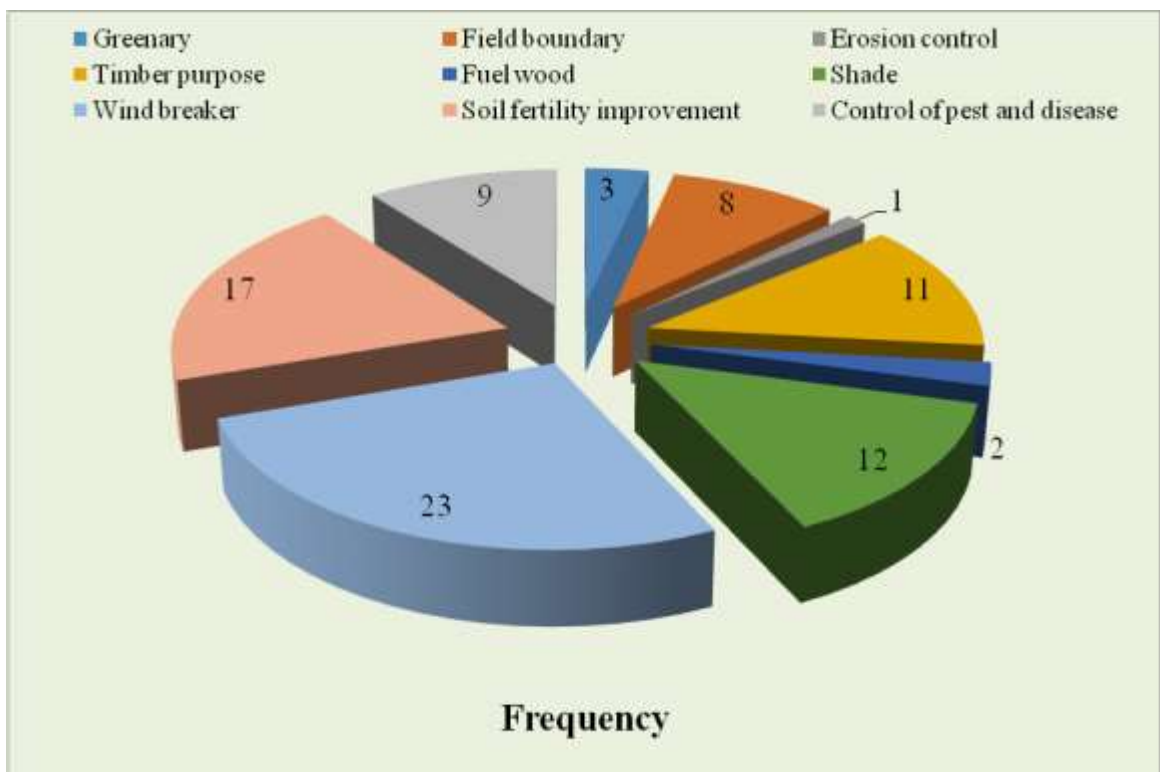


Fig. 9. Distribution of respondents according to their opinion on objectives of *Melia dubia* on plantation

4.2.6.1 Growth at the age of two years (cf. Table 9)

Under rainfed situation, tree height ranged from 3.65 to 4.15 m, bole height from 2.42 to 2.83 m, collar diameter from 8.9 to 9.25 m, diameter at breast height (DBH) from 6.42 to 10.45 cm and wood volume from 0.013 to 0.033 m³ plant⁻¹. Under irrigated condition, tree height varied from 5.12 to 6.74 m, bole height from 3.37 to 4.45 m, collar diameter from 14.5 to 18.2 cm, DBH from 9.78 to 13.42 cm and wood volume from 0.047 to 0.095 m³ plant⁻¹. Average growth indices of *Melia dubia* at age of two years were 5.35 m in case of tree height, 3.54 m in bole height, 15.36 cm in collar diameter and 10.80 cm in DBH with wood volume of 0.050 m³ plant⁻¹.

In conclusion it can be noted that *Melia dubia* is a fast growing tree requires sufficient soil moisture at early stage of growth for better establishment, hence value of growth parameters and volume were higher under irrigated situation than rainfed ecosystem. Similar results are also reported by Nuthan *et al.* (2009) who studied performance of *Melia dubia* in Kanakapur district of Karnataka state.

4.2.6.2 Growth at the age of three years (cf. Table 10)

Under rainfed situation, data recorded on tree height, bole height, collar diameter, DBH and wood volume corresponded to 4.12 m, 2.34 m, 19.7 m, 15.4 m and 0.077 m³ plant⁻¹ respectively. The tree height ranged from 4.20 to 7.16 m, bole height from 3.13 to 4.72 m, collar diameter from 19.98 to 24.57 cm, DBH from 16.40 to 20.84 cm and wood volume from 0.106 to 0.21 m³ plant⁻¹ under irrigated in red soils. On an average, the figures corresponded with tree height, bole height, collar diameter, DBH and wood volume were 5.41 m, 3.88 m, 22.93 cm, 19.19 cm and 0.140 m³ plant⁻¹ respectively.

4.2.6.3 Growth at the age of four years (cf. Table 11)

Observations on tree height, bole height, collar diameter, DBH and volume of *Melia dubia* tree at an age of four years ranged from 5.98 to 7.95 m, 4.56 to 4.72 m, 22.26 to 27.15 cm, 17.85 to 23.56 cm and 0.181 to 0.346 m³ plant⁻¹, respectively with an average of 6.81 m, 5.13 m, 24.88 cm, 22.35 cm and 0.201 m³ plant⁻¹ respectively.

Table 9. Growth parameters and standing volume of *Melia dubia* at the age of two years on farmers' field

Treatment	Irrigated (ha)	Rainfed (ha)	Tree height (m)	Bole height (m)	Collar diameter (cm)	DBH (cm)	Wood volume (m ³ plant ⁻¹)
*F ₁	0	1	4.15	2.83	9.25	6.65	0.014
F ₂	0	2.4	3.98	2.64	8.9	6.42	0.013
F ₃	0	1.2	3.84	2.54	15.8	10.45	0.033
F ₄	0	0.8	3.65	2.42	14.8	9.98	0.029
Average- Rainfed			3.91	2.61	12.19	8.38	0.022
F ₅	1		5.2	3.48	17.8	11.87	0.058
F ₆	1.6		5.92	3.89	15.6	10.58	0.052
F ₇	2		6.23	4.11	18.2	11.05	0.06
F ₈	2		6.71	4.41	17.2	13.42	0.095
F ₉	0.4		5.32	3.51	16.2	11.82	0.058
F ₁₀	4		6.45	4.25	17.4	12.58	0.08
F ₁₁	2		6.74	4.45	16.2	12.98	0.089
F ₁₂	0.4		5.12	3.37	17.8	12.82	0.066
F ₁₃	2.2		6.21	4.13	14.5	9.78	0.047
Average- Irrigated			5.99	3.96	16.77	11.88	0.067
Average			5.35	3.54	15.36	10.80	0.05

* F with number indicates name of the farmer mentioned against the Sl.No in Annexure-1b

Table 10. Growth parameters and standing volume of *Melia dubia* at the age of three years on farmers' field

Treatment	Irrigated (ha)	Rainfed (ha)	Tree height (m)	Bole height (m)	Collar diameter (cm)	DBH (cm)	Wood volume (m ³ plant ⁻¹)
F ₁₄	-	0.8	4.12	2.34	19.7	15.4	0.077
F ₁₅	0.8	-	4.77	3.13	22.8	20.84	0.163
F ₁₆	2	-	4.58	3.56	22.02	17.2	0.106
F ₁₇	1.68	-	4.42	3.92	23.55	17.46	0.106
F ₁₈	2.4	-	4.2	3.78	19.98	15.45	0.079
F ₁₉	1	-	5.98	3.94	24.03	18.86	0.167
F ₂₀	2	-	6.81	4.47	21.06	16.4	0.144
F ₂₁	6.4	-	7.16	4.72	24.57	19.31	0.21
Average- Irrigated			5.42	3.93	22.57	17.93	0.139
Average			5.41	3.88	22.93	18.19	0.14

* F with number indicates name of the farmer mentioned against the Sl.No in Annexure-1b

4.2.6.4 Growth at the age of five years (cf. Table 12)

At the five years, *Melia dubia* tree height, bole height, collar diameter, DBH ranged from 7.24 to 9.23 m, 5.53 to 6.84 m, 29.36 to 33.87 cm, 24.52 to 28.40 cm respectively with wood volume from 0.389 to 0.532 m³ plant⁻¹. On an average *Melia dubia* tree exhibited the value of tree height of 8.04 m, bole height of 6.29 m, collar diameter of 31.23 cm, DBH of 26.43 cm and wood volume of 0.440 m³ plant⁻¹.

4.2.6.5 Growth at the age of six years (cf. Table 13)

Observations on *Melia dubia* growth parameters and volume of tree were recorded both in rainfed and irrigated conditions. Under rainfed situation, data was collected from one farmer which recorded tree height of 7.14 m, bole height of 6.12 m, collar diameter of 30.12 cm, DBH of 21.04 cm and wood volume of 0.248 m³ plant⁻¹ while, an average growth parameter under irrigated conditions stood at 9.13 m, 6.83 m, 35.31 cm, 30.16 cm and 0.664 m³ plant⁻¹ of tree height, bole height, collar diameter, DBH and wood volume respectively. On an average, the figures corresponded with tree height, bole height, collar diameter, DBH and wood volume were 8.73 m, 6.69 m, 30.27 cm, 30.27 cm and 0.581 m³ plant⁻¹ respectively.

4.2.6.6 Growth at the age of eight years (cf. Table 14)

At the eight years, data recorded on tree height, bole height, collar diameter, DBH and wood volume corresponds to 11.54 m, 6.89 m, 41.05 cm, 31.08 cm and 0.875 m³ plant⁻¹, respectively.

Regarding estimation of yield obtained from 8th year plantation by considering volume of tree was 0.875 m³ plant⁻¹ and yield was about 803.25 m³ ha⁻¹. The present value of timber is Rs 125 per cubic feet or Rs 3500 plant⁻¹, expecting around Rs 32,13,000 ha⁻¹.

In conclusion, it can be noted that growth and volume of *Melia dubia* recorded under irrigated ecosystem (red soils) was higher than that of rainfed ecosystem, thus indicating that the species require enough soil moisture, nutrient and sunlight during its growth particularly in early period.

Table 11. Growth parameters and standing volume of *Melia dubia* at the age of four years on farmers' field

Treatment	Irrigated (ha)	Tree height (m)	Bole height (m)	Collar diameter (cm)	DBH (cm)	Wood volume (m ³ plant ⁻¹)
F ₂₂	0.8	6.61	4.95	22.26	23.54	0.288
F ₂₃	0.8	5.98	4.56	25.76	23.08	0.250
F ₂₄	0.8	6.13	5.12	24.88	19.80	0.189
F ₂₅	3.2	6.95	5.42	26.61	19.84	0.215
F ₂₆	2	7.22	5.27	22.58	17.85	0.181
F ₂₇	0.4	7.95	5.45	27.15	23.56	0.346
Average		6.81	5.13	24.88	22.35	0.245

Table 12. Growth parameters and standing volume of *Melia dubia* at the age of five years on farmers' field

Treatment	Irrigated (ha)	Tree height (m)	Bole height (m)	Collar diameter (cm)	DBH (cm)	Wood volume (m ³ plant ⁻¹)
F ₂₈	0.8	9.23	6.11	33.87	27.09	0.532
F ₂₉	3.2	8.23	5.53	30.4	24.52	0.389
F ₃₀	0.8	7.89	6.37	29.36	25.17	0.393
F ₃₁	2	7.62	6.84	31	28.4	0.482
F ₃₂	3	7.24	6.59	31.52	26.98	0.414
Average		8.04	6.29	31.23	26.43	0.44

Table 13. Growth parameters and standing volume of *Melia dubia* at the age of six years on farmers' field

Treatment	Irrigated (ha)	Rainfed (ha)	Tree height (m)	Bole height (m)	Collar diameter (cm)	DBH (cm)	Wood volume (m ³ plant ⁻¹)
F ₃₃	0	1.4	7.14	6.12	30.12	21.04	0.248
F ₃₄	1.2		10.34	6.87	36.37	32.58	0.861
F ₃₅	2.4		9.22	6.18	32.35	27.45	0.545
F ₃₆	1		8.84	7.14	36.12	33.65	0.786
F ₃₇	3.2		8.11	7.12	36.4	26.96	0.463
Average irrigated			9.13	6.83	35.31	30.16	0.664
Average			8.73	6.69	30.27	28.12	0.581

Table 14. Growth parameters and standing volume of *Melia dubia* at the age of four years on farmers' field

Treatment	Irrigated (ha)	Tree height (m)	Bole height (m)	Collar diameter (cm)	DBH (cm)	Wood volume (m ³ plant ⁻¹)
F ₃₈	2.4	11.54	6.89	41.05	31.08	0.875

* F with number indicates name of the farmer mentioned against the Sl.No in Annexure-1b

4.3 Experiment-II: Effect of pre-sowing seed treatment on germination of *Melia dubia*

The demand for nursery seedlings has increased manifold for planting under social forestry programme with the massive afforestation programme taken up by the government agencies. Lacks of standard nursery techniques hinder such attempts. Even poor natural regeneration and low rate of seed germination make the situation worse in case of certain species. Raising quality seedlings in nursery is one of the pre-requisite for establishing a successful plantation. It should be cost effective and as far as possible, the technology should be easily adoptable by the people. *Melia dubia* has been screened as one of the best alternate of pulpwood species. Being an indigenous species, it has great potential to meet the demands of pulp-wood and other needs. Although regeneration of this species under natural conditions is very high, the seeds generally exhibited very low germination due to hard seed coat under laboratory conditions. Vegetative means of propagation is difficult. Studies carried out so far indicated that the germination under nursery condition ranges from 14 to 28 per cent. Even many physical and chemical methods used to induce and enhance seed germination were found to be futile. Therefore, the experiment was conducted for two years during 2018 and 2019 under shadenet with an objective of enhancing the germination percentage. The results were highlighted based on the pooled data as similar trend was seen in both the years. The data in individual years are highlighted when behaved differently. Some weather parameters also influenced on germination of *Melia dubia* seeds.

4.3.1 Seed germination

4.3.1.1 Imbibition period (day) (cf. Table 15 and Fig. 10)

Seed imbibition period differed significantly in both the years and pooled analysis due to different pre sowing seed treatment practices.

In pooled data, significantly lower imbibition period (35.17 days) was observed in seeds soaked in KNO_3 solution (200 m moles for 24 hrs) followed by soaking of seeds in cowdung slurry for 12 days (39.0 days) when compared to all the treatments. Thus, indicating early or quick germination of *Melia dubia* seeds due to these treatments. Significantly higher imbibition period (52.33 days) was observed in control plot as compared to other treatments except soaking of seeds in cold water for 4 days (49.33

days) and 8 days (48.00 days). Similar trend was also observed in both the years. In general, early with lower values of imbibitions period was during 2018 than 2019 season due to prevailing of high temperature and humidity during the experimental period. Similar results of early seed germination were also reported by Sinhababu *et al.* (2007) in *Acacia holosericea* and *Cassia fistula* and Sujatha (2014) in *Melia azeradach* due to seed soaking in KNO₃ solution while, Chaya and Channabasappa (2015) in *Lagerstroemia lanceolata* and Suthesh *et al.* (2016) in *Santalum album* seeds due to soaking of seeds in cowdung slurry.

4.3.1.2 Total germination period (day) (cf. Table 15 and Fig. 10)

In pooled data, *Melia dubia* seeds took significantly more number of days for germination in control plot (75.00 days) over all other treatments, except seeds soaked in cold water for 4, 8 and 12 days and seeds soaked in biogas slurry for 4 days. Seeds soaked in KNO₃ solution (200 m moles for 24 hrs) and cowdung slurry had significant effect on germination period, thus recorded significantly lower total number of days for germination (66.50 and 67.50 days, respectively) when compared to all other treatments. Similar trends were also seen in both the years. These pre-sowing treatments initiated early germination and reduced period of germination by facilitating enhanced imbibition of water into cotyledons and hastened the biochemical reactions, in turn increased the mean daily germination and peak value. Further, rapid release of enzymes during the process geared up the system that was already in motion, so that the seeds sown undergone developmental changes rapidly and finally lead to higher germination with reduced germination period. Sinhababu *et al.* (2007) in *Acacia holosericea* and *Cassia fistula* and Sujatha (2014) in *Melia azeradach* observed that number of days taken to reach 100 per cent germination species reduced in KNO₃ treatment. These results are also in agreement with those of Manasi (2011) and Chaya and Channabasappa (2015) who reported effect of KNO₃ solution and cowdung slurry, respectively in *Lagerstroemia lanceolata* in reducing total germination period.

4.3.1.3 Germination percentage (cf. Table 15 and Fig.10)

Germination of *Melia dubia* seeds was differed significantly due to different pre-sowing treatment methods. In pooled data, seeds soaked in KNO₃ solution (200 m moles for 24 hrs) recorded significantly higher seed germination percentage (45.37) when

compared to all the treatments except the seeds soaked in cow dung slurry (42.59) and biogas slurry (39.81) for 12 days. There was no significant difference in germination percentage when seeds were soaked in cowdung and biogas slurry for 8 and 12 days. Germination percentage of seeds soaked in cold water for 12 days was significantly superior over control plot except with the seeds soaked in cold water for 4 and 8 days, seeds soaked in cowdung for 4 and 8 days, seeds soaked in biogas slurry for 4 and 8 days in both the years and pooled data. Significantly lower germination percentage was observed in control plot (19.44) which was on par with soaking of seeds in cold water for 4 days and 8 days.

The significant increase in germination percentage with KNO_3 solution over other seed treatment practices may be due to enhanced imbibition of water into cotyledons and shift in respiratory metabolism to pentose phosphate pathway due to oxidized form of nitrogen present in KNO_3 . Another reason for the positive effect of KNO_3 on seed germination was related to creating a balance between hormonal ratios in seed reducing the growth preventable materials, like ABA (Rahayu Wulandini and Nurin Widyani, 2007). Similar results were also reported by Sinhababu *et al.* (2007) where, nitrogenous substance like KNO_3 was effective in increasing germination percentage of *Acacia holosericea* and *Cassia fistula*. Further, the number of days taken to reach 100 per cent germination in these species was also reduced with KNO_3 treatment. Similarly, Dinesh Giri and Sushma Tamta (2012) who reported that the seeds of *Hedychium spicatum* treated with KNO_3 (50 mM) recorded maximum germination in nursery condition while, Sujatha (2014) recorded maximum germination (84.0%) of *Melia azeridech* in 200 Molar KNO_3 solution. The other quality indices *viz.*, mean daily germination, germination value and germination rate of seeding were also maximum with this treatment.

Further, the increase in germination percentage with cowdung and biogas slurry might be due to increased microbial population, presence of anaerobic condition and moderate temperature which triggered the germination process in the seed. Cowdung attracts termites which in turn feed on fibrous seed coat, resulting in increased germination. Similar results were also reported by Basavaraj *et al.* (2002), Krishna *et al.* (2011) and Khushboo Tandon *et al.* (2019) in *Elaeocarpus munronii*, *Melia dubia* and *Tamarindus indica* species respectively. Where cowdung treatment recorded maximum germination percentage compared to control.

Many evidences are also available in literature wherein germination of tropical hard coated seeds was enhanced by immersion in cold and hot water (Gupta and Thapliyal, 1974 and Hartmann and Kestu, 1978). Further, seeds of *Hippophae salicifolia* treated with hot water at 80°C for 10 minutes resulted in maximum germination per cent. Whereas, in case of *Hippophae rhamnoides*, seeds treated with cold water resulted in maximum germination per cent. Similar results were observed by Kumar and Gopal (1975), Naidu and Mastan (2001), Sankhyan *et al.* (2005), Hossain *et al.* (2005), Neeraj Khera and Saxena (2008). Ramkrishna Hegde *et al.* (2009) reported that water treatment increased the germination in *Mimusops elengi*. Srinidhi *et al.* (2011) opined that alternate dipping in hot and cold water for five minutes each repeated thrice increased the germination percentage significantly in *Acacia holosericea*. Murugesh (2011) observed significant difference among seed treatments where in cold water treatment for 48 hours recorded highest seed germination in *Grevillea robusta*.

4.3.1.4 Germination value (cf. Table 15)

The different pre-sowing seed treatments had significant effect on germination value of *Melia dubia* seeds in both the years and pooled analysis. In pooled data, significantly higher germination value was observed when seeds were soaked in KNO₃ solution (2.77) over all the treatments except with seeds soaked in cowdung for 12 days (2.56). During 2018 and 2019 former treatment showed significant superiority over all the treatments except seeds soaked in cowdung and biogas slurry for 12 days. Significantly lower germination value (0.52) was exhibited by control plot when compared to rest of the treatments. Significant improvement in germination value due to seed soaking in KNO₃ solution was also reported by Chaya and Channabasappa (2015) in *Lagerstroemia lanceolata* and Sujatha (2014) in *Melia azeridech* species and seed soaking in cowdung slurry in *Melia dubia* species as reported by Krishna *et al.* (2011).

4.3.1.5 Germination energy (%) (cf. Table 15)

Germination energy is a measure of the speed of germination. It is assumed of the speed vigour of the seed and of the seedling which it produces. Different pre-sowing treatments exhibited significant differences in germination energy of seeds in both the years and also in pooled analysis. In pooled data, significantly higher germination energy was recorded when seeds were soaked in KNO₃ solution (40.83 %) over all the

Table 15. Effect of pre-sowing seed treatments on imbibition period, total germination period, germination percentage, germination value and germination energy of *Melia dubia*

Treatments	Imbibition period (day)			Total germination period (day)			Germination (%)			Germination value			Germination energy (%)		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
T₁	49.33	55.33	52.33	74.33	75.67	75.00	20.37	18.52	19.44	0.55	0.49	0.52	18.33	16.67	17.50
T₂	47.33	51.33	49.33	73.33	73.67	73.50	25.93	24.07	25.00	1.06	0.98	1.02	23.33	21.67	22.50
T₃	46.00	50.00	48.00	72.33	73.33	72.83	27.78	25.93	26.85	1.15	1.06	1.11	25.00	23.33	24.17
T₄	44.67	48.67	46.67	70.33	72.67	71.50	29.63	27.78	28.70	1.68	1.53	1.60	26.67	25.00	25.83
T₅	44.00	47.00	45.50	69.00	68.33	68.67	35.19	31.48	33.33	2.04	1.85	1.94	31.67	28.33	30.00
T₆	41.67	44.00	42.83	67.33	68.33	67.83	38.89	33.33	36.11	2.31	1.95	2.13	35.00	30.00	32.50
T₇	36.67	41.33	39.00	64.67	68.33	66.50	44.44	40.74	42.59	2.74	2.39	2.56	40.00	36.67	38.33
T₈	44.33	48.00	46.17	73.00	70.33	71.67	31.48	27.78	29.63	1.72	1.59	1.66	28.33	25.00	26.67
T₉	42.67	45.67	44.17	71.33	69.00	70.17	37.04	29.63	33.33	2.08	1.72	1.90	33.33	26.67	30.00
T₁₀	41.00	42.67	41.83	66.67	72.00	69.33	40.74	38.89	39.81	2.45	2.16	2.30	36.67	35.00	35.83
T₁₁	33.67	36.67	35.17	65.67	65.33	65.50	46.30	44.44	45.37	2.82	2.73	2.77	41.67	40.00	40.83
S.Em±	01.34	01.27	01.11	01.19	1.02	0.76	2.50	2.56	1.99	0.12	0.15	0.10	2.25	2.30	1.79
C.D. at 1%	05.36	05.07	04.43	04.76	4.05	3.02	9.95	10.20	7.95	0.48	0.59	0.40	8.96	9.18	7.15

T₁ : Control

T₂ : Soaking of seeds in cold water (4 days)

T₃ : Soaking of seeds in cold water (8 days)

T₄ : Soaking of seeds in cold water (12 days)

T₅ : Soaking of seeds in cowdung slurry (4 days)

T₆ : Soaking of seeds in cowdung slurry (8 days)

T₇ : Soaking of seeds in cowdung slurry (12 days)

T₈ : Soaking of seeds in biogas slurry (4 days)

T₉ : Soaking of seeds in biogas slurry (8 days)

T₁₀ : Soaking of seeds in biogas slurry (12 days)

T₁₁ : Soaking of seeds in KNO₃ solution (200 m moles for 24 hrs)

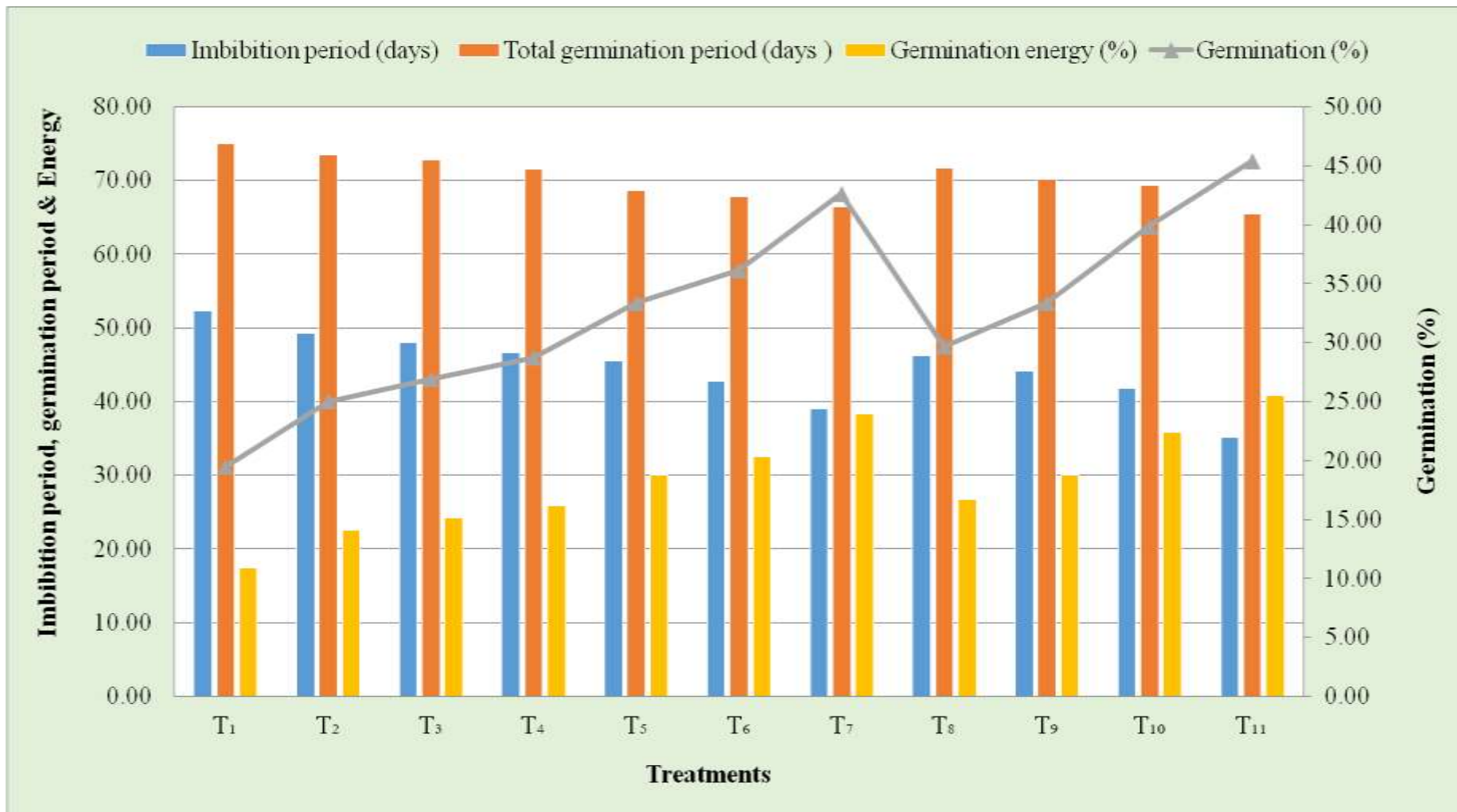


Fig. 10. Effect of seed soaking treatment on imbibition period, total germination period, germination energy and germination percentage of *Melia dubia* seedlings

treatments, except treatments where seeds soaked in cowdung slurry (38.83 %) and biogas slurry (35.83 %) for 12 days. Significantly lower germination energy (17.50 %) was exhibited in control plot.

These results are in line with findings of Anand *et al.* (2012) who observed the highest germination value and germination energy in *Melia dubia* with cowdung treatment. Similarly, Sutteesh *et al.* (2016) also recorded the highest germination energy due to soaking of *Santalum album* seeds in cowdung slurry.

4.3.2 Growth performance

4.3.2.1 Shoot length (cm) (cf. Table 16)

Significant variation in shoot length of *Melia dubia* seedling was observed due to different pre-sowing treatments. In pooled data, shoot length at the end of germination period was found to be significantly higher with seeds soaked in cowdung slurry for 12 days (28.2 cm) over all other treatments except seeds soaked in biogas slurry for 12 days (27.3) and cowdung slurry for 8 days during 2019 (28.5 cm) and seeds soaked in KNO₃ solution during 2018 (24.00 cm). Significantly lower shoot length (16.6 cm) was observed in control plot when compared to all the treatments.

4.3.2.2 Root length (cm) (cf. Table 16)

Pre-sowing seed treatments exhibited significant differences in root length of seedlings in both the years and in pooled analysis. In pooled data, seeds soaked in cowdung slurry for 12 days (10.2 cm) showed its significant superiority in root length over all other treatments, except seeds soaked in cowdung for 8 days (8.9 cm), biogas slurry for 12 days (9.5 cm) and seeds soaked in KNO₃ solution (9.3 cm). Significantly lower root length (6.0 cm) was recorded in control plot when compared to all the treatments. Similar trend was followed during both the years of study.

4.3.2.3 Total length of seedling (cm) (cf. Table 16 and Fig. 11)

Total length of seedling was significantly influenced by pre-sowing seed treatment methods in both the years and pooled analysis. Significantly higher length of seedling was recorded with the treatment of seeds soaked in cowdung slurry for 12 days (39.3 cm) over all other treatments except seeds soaked in biogas slurry for 12 days (36.8 cm). Next best

treatment was seeds soaked in cowdung slurry for 8 days (35.5 cm) followed by treatments of seeds soaked in KNO₃ solution (35.0 cm) and biogas slurry for 8 days (33.7 cm). Significantly lower length of seedling was observed in control plot (22.5 cm) over the rest of other treatments.

4.3.2.4 Collar diameter (mm) (cf. Table 16)

Pre-sowing seed treatment methods exhibited significant differences in value of collar diameter of *Melia dubia* seedlings during 2018 and 2019 and in pooled analysis. In pooled data, significantly higher seedling collar diameter value (15.7 mm) was recorded in seeds soaked in cowdung slurry for 12 days over all other treatments except seeds soaked in cowdung for 8 days (13.5 mm) and 4 days (12.8 mm) and biogas slurry for 12 days (14.7 mm) and 8 days (13.8 mm) and seeds soaked in KNO₃ solution during 2018 (14.1 mm) and in pooled analysis (15.0 mm). Significantly lower value of collar diameter of seedlings was observed in control plot (10.7 mm). Similar results were also reported by Anand *et al.* (2012) who noticed in *Melia dubia* seedlings due to soaking of seeds in cowdung for seven days, Suthesh *et al.* (2016) in *Santalum album* seedlings with the soaking of seeds in organic treated solution and Agera Stephen *et al.* (2019) in *Eucalyptus camaldulensis* seedlings with the seeds soaking in poultry litter and cowdung.

4.3.2.5 Number of leaves per seedling (cf. Table 16)

Number of leaves per seedling of *Melia dubia* differed significantly due to pre-sowing treatments during 2018 and 2019 and in pooled analysis. In pooled data, significantly higher number of leaves per seedling was observed in seeds soaked in cowdung for 12 days (26.2) over all other treatments except seeds soaked in KNO₃ solution (24.4) and biogas slurry for 12 days (23.0). There were no significant differences observed in number of leaves per seedling between seeds soaked in cowdung slurry for 12 and 8 days during 2019. Control plot produced significantly lower number of leaves per seedling (11.7) over all other treatments.

The positive effect of organic treatments on growth parameters of seedlings was recorded by various researchers. Cowdung attracts termites and micro-organisms which in turn feed on fibrous seed coat resulting in increased germination and growth parameters. Rai *et al.* (1986) reported the beneficial effects of cowdung slurry treatment on germination of *Terminalia tomentosa* and *Pterocarpus santalinus*. Similar results were

Table 16. Effect of pre-sowing seed treatments on seedling growth of *Melia dubia*

Treatments	Shoot length (cm)			Root length (cm)			Total length (cm)			Collar diameter (mm)			Number of leaves seedling ⁻¹		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
T₁	15.4	17.7	16.6	5.6	6.3	6.0	21.0	24.0	22.5	10.0	11.3	10.7	11.3	12.0	11.7
T₂	18.2	21.0	19.6	6.6	7.4	7.0	24.8	28.4	26.6	10.7	12.1	11.4	14.3	16.3	15.3
T₃	18.4	21.1	19.7	7.1	8.1	7.6	25.5	29.2	27.3	10.9	12.4	11.6	16.0	18.2	17.1
T₄	21.3	24.4	22.9	8.5	8.9	8.7	29.8	33.3	31.5	11.4	12.9	12.1	17.3	19.8	18.5
T₅	23.5	27.1	25.3	7.6	8.6	8.1	31.1	35.6	33.4	11.9	13.6	12.8	18.3	22.7	20.5
T₆	24.8	28.5	26.7	8.3	9.4	8.9	33.1	37.9	35.5	12.5	14.5	13.5	19.3	24.0	21.7
T₇	27.1	31.2	29.2	9.6	10.8	10.2	36.7	42.0	39.3	14.7	16.6	15.7	24.0	28.5	26.2
T₈	22.1	25.4	23.7	7.5	8.5	8.0	29.6	33.9	31.7	11.5	13.0	12.3	17.0	19.4	18.2
T₉	23.3	26.9	25.1	8.1	9.2	8.6	31.4	36.0	33.7	13.4	14.3	13.8	19.3	22.0	20.7
T₁₀	25.4	29.2	27.3	8.9	10.1	9.5	34.3	39.3	36.8	13.8	15.6	14.7	21.0	25.1	23.0
T₁₁	24.0	27.5	25.7	8.7	9.8	9.3	32.6	37.3	35.0	14.1	15.9	15.0	22.3	26.4	24.4
S.Em±	0.8	0.9	0.8	0.3	0.3	0.3	0.7	0.9	0.8	0.6	0.7	0.6	1.1	1.2	1.1
C.D. at 1 %	3.1	3.5	3.3	1.2	1.4	1.3	3.0	3.4	3.2	2.6	2.5	2.6	4.2	4.7	4.3

T₁ : Control

T₂ : Soaking of seeds in cold water (4 days)

T₃ : Soaking of seeds in cold water (8 days)

T₄ : Soaking of seeds in cold water (12 days)

T₅ : Soaking of seeds in cowdung slurry (4 days)

T₆ : Soaking of seeds in cowdung slurry (8 days)

T₇ : Soaking of seeds in cowdung slurry (12 days)

T₈ : Soaking of seeds in biogas slurry (4 days)

T₉ : Soaking of seeds in biogas slurry (8 days)

T₁₀ : Soaking of seeds in biogas slurry (12 days)

T₁₁ : Soaking of seeds in KNO₃ solution (200 m moles for 24 hrs)

also obtained by Maithani *et al.* (1991), Sankaranarayanan *et al.* (1994), Prasanna *et al.* (1999), Saini *et al.* (1999), Morpeth and Hall (2000), Naidu and Mastan (2001), Manjunath Gouda (2005) and Lokesh (2007). Krishna *et al.* (2011) and Anand *et al.* (2012) also recorded higher number of leaves per seedling in *Melia dubia* with cowdung seed treatment when compared to control and other treatments.

4.3.3 Seedling biomass production

4.3.3.1 Shoot dry weight (g seedling⁻¹) (cf. Table 17)

Significant difference in shoot dry weight of seedling due to different treatments was observed in both the years of study and in pooled data. In pooled data, significantly higher shoot dry weight (0.77 g seedling⁻¹) was recorded in seeds soaked in cowdung slurry for 12 days when compared to all the treatments except seeds soaked in KNO₃ solution (0.75 g seedling⁻¹) and biogas slurry for 12 days (0.72 g seedling⁻¹) and 8 days (0.66 g seedling⁻¹). They were in turn comparable with each other. Significantly lower shoot dry weight (0.28 g seedling⁻¹) was observed in control plot. Similar trend was followed during 2018 but during 2019, apart from this trend, seeds soaked in cowdung slurry for 12 days showed comparable results with seeds soaked in cowdung slurry for 8 days.

4.3.3.2 Root dry weight (g seedling⁻¹) (cf. Table 17)

Pre-sowing seed treatment methods exhibited significant variations in root dry weight of *Melia dubia* seedlings. In pooled data, significantly higher root dry weight was recorded with seeds soaked in cowdung slurry for 12 days (0.63 g seedling⁻¹) when compared to all the treatments except KNO₃ solution (0.61 g seedling⁻¹), biogas slurry for 12 days (0.59 g seedling⁻¹) and 8 days (0.54 g seedling⁻¹) and seeds soaked in cowdung slurry for 8 days (0.52 g seedling⁻¹). Significantly lower root dry weight was observed in control plot (0.23 g seedling⁻¹) when compared to all the treatments except seeds soaked in cold water for 4, 8 and 12 days. Similar trend was followed in both the years of the study.

4.3.3.3 Total dry weight (g seedling⁻¹) (cf. Table 17)

Total dry weight of *Melia dubia* seedlings was differed significantly due to various treatments during 2018 and 2019 seasons and also in pooled analysis. In pooled data, seeds soaked in cowdung for 12 days exhibited significantly higher total dry weight (1.40 g seedling⁻¹) over seeds soaked in control (0.50 g seedling⁻¹), seeds soaked in cold water for 4 days (0.63 g seedling⁻¹), 8 days (0.67 g seedling⁻¹), 12 days (0.80 g seedling⁻¹), seeds soaked in cowdung for 4 days (0.98 g) and seeds soaked in biogas slurry for 4 days (1.09 g seedling⁻¹), which in turn they were comparable each other. The next best treatment was seeds soaked in KNO₃ solution (1.36 g seedling⁻¹) followed by biogas slurry for 12 days (1.31 g seedling⁻¹) and 8 days (1.19 g seedling⁻¹) and seeds soaked in cowdung slurry for 8 days (1.15 g seedling⁻¹).

These results are in conformity with the findings of Mane *et al.* (2018) who reported that custard apple seeds when soaked in cowdung slurry resulted in higher dry weight of seedling, length of root, primary roots, secondary roots and fresh and dry weight of root over the control treatment.

4.3.3.4 Vigour index (cf. Table 17 and Fig. 11)

Pre-sowing seed treatments of *Melia dubia* significantly influenced the vigour index of seedlings during 2018 and 2019 seasons and in pooled analysis. In pooled data, seeds soaked in cowdung for 12 days showed its significant superiority in vigour index (1674) over all the treatments, except seeds soaked in biogas slurry for 12 days (1587) and seeds soaked in KNO₃ solution (1464), which were comparable with each other. Comparable vigour index due to seeds soaked in water for 12 days, cowdung for 8 days and biogas slurry for 4 and 8 days was observed in both the years and in pooled data. This indicated that water also played an important role in improving germination percentage and thereby enhancing growth and vigour index of seedlings. Significantly lower vigour index value (436) was observed in control plot when compared to all other treatments.

These results are in agreement with results obtained by Krishna *et al.* (2011) who obtained maximum seedling length and vigour index of *Melia dubia* with cowdung seed treatment. Anand *et al.* (2012) observed higher shoot, root, total seedling dry weight and vigour index in *Melia dubia* seedlings when seeds were soaked in cowdung and Suthesh *et al.* (2016) in *Santalum album* seeds due to soaking of seeds in cowdung slurry

Table 17. Effect of pre-sowing seed treatments on dry weight and vigour index of *Melia dubia* seedlings

Treatments	Shoot dry weight (g seedling ⁻¹)			Root dry weight (g seedling ⁻¹)			Total dry weight (g seedling ⁻¹)			Vigour Index		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
T₁	0.26	0.29	0.28	0.21	0.25	0.23	0.47	0.54	0.50	425	445	436
T₂	0.33	0.36	0.34	0.27	0.28	0.28	0.59	0.64	0.63	646	683	666
T₃	0.34	0.40	0.37	0.28	0.33	0.30	0.62	0.72	0.67	712	761	738
T₄	0.42	0.46	0.44	0.34	0.37	0.36	0.76	0.83	0.80	882	928	906
T₅	0.50	0.58	0.54	0.41	0.47	0.44	0.90	1.05	0.98	1094	1119	1111
T₆	0.59	0.68	0.63	0.48	0.56	0.52	1.07	1.24	1.15	1290	1262	1283
T₇	0.75	0.79	0.77	0.62	0.64	0.63	1.37	1.43	1.40	1628	1710	1674
T₈	0.56	0.65	0.60	0.46	0.53	0.49	1.01	1.18	1.09	930	942	939
T₉	0.61	0.70	0.66	0.50	0.57	0.54	1.12	1.27	1.19	1162	1067	1123
T₁₀	0.67	0.77	0.72	0.55	0.63	0.59	1.21	1.40	1.31	1401	1521	1464
T₁₁	0.71	0.78	0.75	0.58	0.66	0.61	1.30	1.44	1.36	1509	1661	1587
S.Em±	0.03	0.03	0.04	0.03	0.04	0.03	0.07	0.08	0.07	80	90	67
C. D. at 1 %	0.15	0.17	0.16	0.12	0.12	0.13	0.28	0.29	0.28	320	360	266

T₁ : Control

T₂ : Soaking of seeds in cold water (4 days)

T₃ : Soaking of seeds in cold water (8 days)

T₄ : Soaking of seeds in cold water (12 days)

T₅ : Soaking of seeds in cowdung slurry (4 days)

T₆ : Soaking of seeds in cowdung slurry (8 days)

T₇ : Soaking of seeds in cowdung slurry (12 days)

T₈ : Soaking of seeds in biogas slurry (4 days)

T₉ : Soaking of seeds in biogas slurry (8 days)

T₁₀ : Soaking of seeds in biogas slurry (12 days)

T₁₁ : Soaking of seeds in KNO₃ solution (200 m moles for 24 hrs)

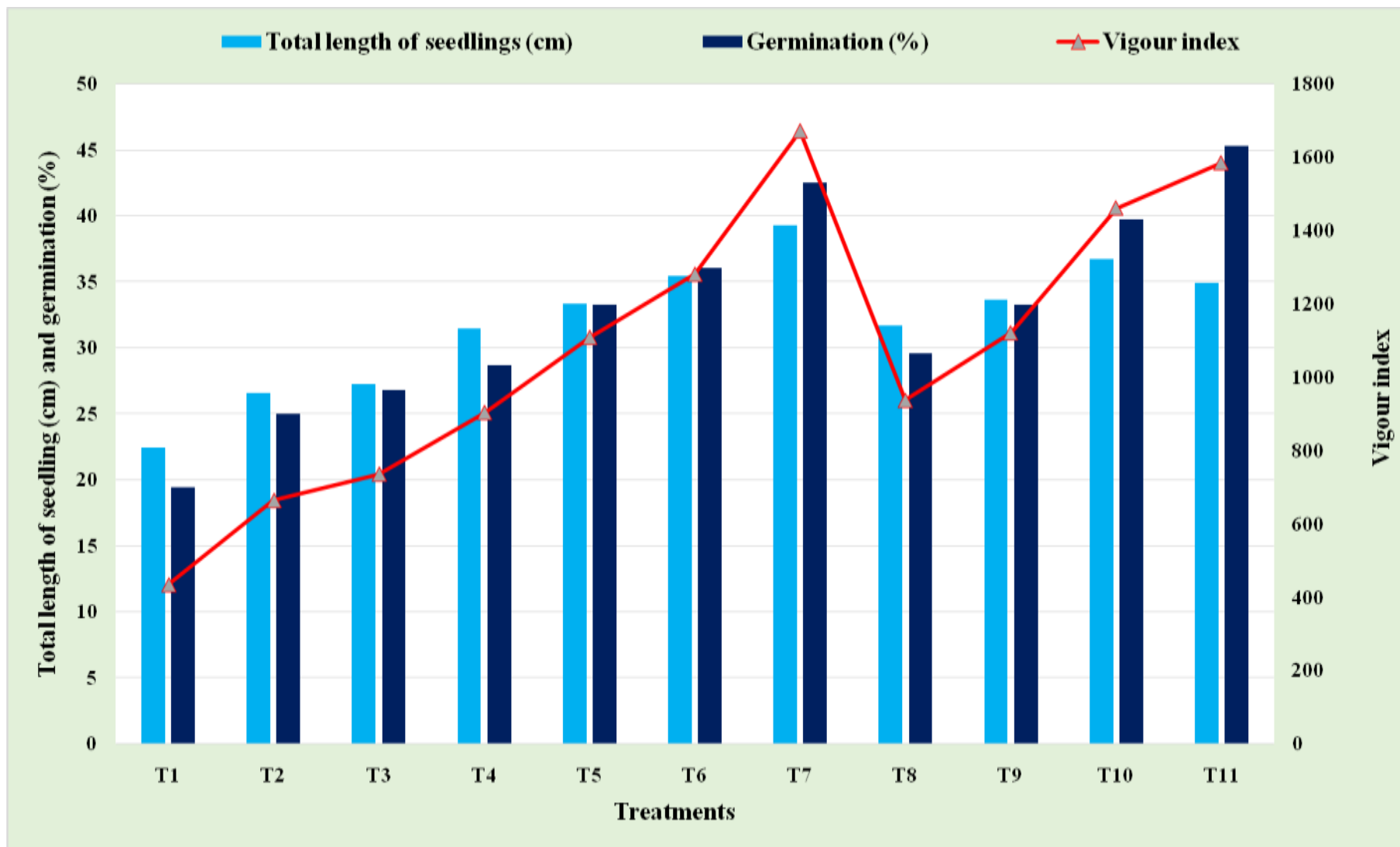


Fig. 11. Effect of seed soaking treatment on total length of seedlings, germination (%) and vigour index of *Melia dubia* seedlings



Plate 1a: Seeds soaking in cowdung slurry for 12 days



Plate 1b Seeds soaking in KNO₃ solution for 24 hrs

Plate 1. Effect of pre-sowing seed treatment on germination of *Melia dubia*



Plate 1c: General view of experiment II before imposing of treatments



Plate 1d: General view of experiment II after imposing of treatments



Plate 1e: Control plot

Plate 1. Effect of pre-sowing seed treatment on germination of *Melia dubia*



Plate 1f: Seeds soaking in cowdung slurry for 12 days



Plate 1g: Seeds soaking in KNO₃ solution for 24 hrs

Plate 1. Effect of pre-sowing seed treatment on germination of *Melia dubia*

Thanuja *et al.* (2018) who reported that pre-sowing treatments with H₂SO₄ (2%) and cowdung slurry (1:1) showed significantly improved in germination and seedling vigour of *Pterocarpus marsupium* seedlings than all other treatments. Rai *et al.* (2018) observed increase in vigour index of *Manilkara hexandra* seeds due to soaking of seeds in KNO₃ solution when compared with control.

Pre-sowing treatments of seeds of *Melia dubia* with KNO₃ or cowdung slurry or biogas slurry are cheap and promising ones. These inputs are eco-friendly and depending on the availability they can be utilized for large scale propagation of *Melia dubia*.

4 Experiment - III: Performance of foxtail millet as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

4.4.1 Growth components

The data on growth components of foxtail millet *viz.*, plant height, number of leaves, number of tillers, leaf area, leaf area index, dry matter production and its accumulation in leaves, stem and reproductive parts and growth indices as influenced by different organic nutrient management practices in agroforestry system and foxtail millet cultivation with recommended organic nutrient schedule without tree component are presented here.

The prominence was given to present the results of the pooled data instead of individual years as similar trend was observed in both the years. The data in individual years are highlighted when behaved differently.

4.4.1.1 Plant height (cm) (cf. Table 18)

Plant height increased with the advancement of crop age reaching the highest at harvest and was significantly influenced by different organic nutrient management practices in *Melia dubia* based agroforestry system during both the years and in pooled data at 30 and 60 DAS and at harvest.

In pooled data, at 30 DAS, sole foxtail millet with recommended organic nutrient management practice without tree component recorded significantly higher plant height (31.01 cm) over all other treatments of agroforestry system (18.92 to 27.68 cm). Among the treatments with agroforestry system, FYM + poultry manure + panchagavya

alternated with vermiwash (T₁₀) recorded significantly higher plant height (27.68 cm) over no organic manures application (18.92 cm), FYM (22.68 cm) and FYM + poultry manure + vermiwash (25.34 cm). The treatment which received no organic manures recorded significantly lower plant height (18.92 cm) over all other treatments. Effects due to other treatments were intermediary.

At 60 DAS, in pooled data, significantly higher plant height was recorded with treatment of sole foxtail millet without tree component along with organic nutrient management schedule (98.20 cm) when compared to all treatments in agroforestry system (59.19 to 88.47 cm). Among the treatments with agroforestry system, FYM + poultry manure + panchagavya alternated with vermiwash spray showed its significant superiority (88.47 cm) than all other rest of the treatments except FYM + poultry manure (85.33 cm), FYM + vermicompost + panchagavya alternated with vermiwash spray (83.24 cm), FYM + poultry manure + panchagavya (82.83 cm), FYM + vermicompost + panchagavya (80.85 cm), while, no organic manure application plot recorded significantly lower plant height (59.19 cm) than all other treatments.

At harvest, treatment comprising of sole foxtail millet with recommended organic nutrient management practice without tree association recorded significantly higher plant height (121.36 cm) over the different treatments with tree component (74.34 cm to 109.85 cm). The best treatment with tree combination was FYM + poultry manure + panchagavya alternated with vermiwash spray (109.85 cm) which was on par with FYM + poultry manure (104.50 cm), FYM + vermicompost + panchagavya alternated with vermiwash spray (104.34 cm), FYM + poultry manure + panchagavya spray (104.23 cm) and FYM + vermicompost + panchagavya (101.06 cm). Significantly lower plant height was noticed with the treatment receiving no organic manures (74.34 cm) when compared to all other treatments. Other rest of the treatments were intermediary in their effect.

Significant increase in plant height with the treatments of application of FYM + poultry manure and FYM + vermicompost with foliar spray of panchagavya or vermiwash alone (T₅ to T₈) or panchagavya alternated with vermiwash (T₉ and T₁₀) was due to greater availability and steady release of nutrients from organic sources and also nitrogen content in organics increased the chlorophyll content as it is a constituent and it was increased the photosynthesis and resulted in increased plant height. The increased activity of meristematic cells and cell elongation with application of panchagavya

Table 18. Plant height at different growth stages of foxtail millet as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

Treatments	Plant height (cm)								
	30 DAS			60 DAS			At harvest		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
T₁	17.77	20.08	18.92	55.84	62.54	59.19	69.80	78.88	74.34
T₂	21.30	24.07	22.68	67.10	75.82	71.46	83.87	94.77	89.32
T₃	24.27	26.67	25.47	74.34	84.00	79.17	92.93	105.01	98.97
T₄	25.93	28.23	27.08	81.69	88.98	85.33	99.21	109.80	104.50
T₅	24.10	27.23	25.67	75.92	85.78	80.85	94.89	107.23	101.06
T₆	24.63	27.84	26.23	77.67	87.99	82.83	97.87	110.59	104.23
T₇	24.23	26.59	25.41	73.19	81.97	77.58	91.48	103.69	97.58
T₈	23.97	26.71	25.34	74.45	84.12	79.28	93.06	105.15	99.10
T₉	25.77	27.88	26.82	78.16	88.32	83.24	97.70	110.98	104.34
T₁₀	26.20	29.16	27.68	83.79	93.14	88.47	102.66	117.03	109.85
T₁₁	29.27	32.75	31.01	92.21	104.20	98.20	113.42	129.30	121.36
S.Em ±	0.76	0.95	0.79	2.50	2.66	2.44	3.01	3.20	3.10
C. D. at 5%	2.23	2.80	2.32	7.38	7.84	7.45	8.89	9.45	9.14

DAS: Days after sowing

T₁ : No organic manure (Control)

T₂ : FYM equivalent to 100 % RDN

T₃ : FYM (50%) + Vermicompost (50%) equivalent to 100 % RDN

T₄ : FYM (50%) + Poultry manure (50%) equivalent to 100 % RDN

T₅ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₆ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₇ : **T₃** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₈ : **T₄** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₉ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₀ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₁ : Sole foxtail millet without tree component

comprises coconut water which contains kinetin (growth promoter) which might have increased cytokinin in the leaf as a consequence there was increase in plant height. These results are corroborated with the findings of Sonawane *et al.* (2016), Upendranaik *et al.* (2018) and Priya and Sathyamoorthi (2019) who reported increased plant height with organics along with foliar spray of panchagavya and vermiwash alone.

The plant height of foxtail millet was affected by shade of *Melia dubia* tree, which was nullified by balanced supply of nutrients through organics. Similar results were also reported by Panneer and Bheemaiah (2005), Jat and Thakur (2010), Sehgal (2011), and Umrao *et al.* (2013) with improving growth of intercrops in agroforestry system through integrated organic nutrient management practices.

4.4.1.2 Number of leaves per plant (cf. Table 19)

Significant variations were observed with regard to number of leaves per plant due to organic nutrient management practices during both the years and in pooled data in *Melia dubia* based agroforestry system.

In pooled data, at 30 DAS, sole foxtail millet with recommended organic nutrient management practice without tree component produced significantly higher number of leaves per plant (4.98) over all other treatments of agroforestry system (3.53 to 4.29). In agroforestry system, FYM + poultry manure + panchagavya alternated with vermiwash produced significantly higher number of leaves per plant (4.29) over no organic manurial treatment (3.53), FYM (3.74) and FYM + vermicompost + vermiwash spray (3.97). Effects due to other treatments were intermediary.

At 60 DAS, in pooled data, significantly higher number of leaves per plant was recorded with treatment of sole foxtail millet with recommended organic nutrient practices without tree component (25.84) when compared to all other treatments of agroforestry system (17.96 to 22.68). Among the treatments with agroforestry system, FYM + poultry manure + panchagavya alternated with vermiwash spray (22.68) showed its significant superiority than all other treatments except FYM + poultry manure + vermiwash spray (22.41), FYM + poultry manure + panchagavya spray (22.16), FYM + poultry manure (21.86), FYM + vermicompost + panchagavya alternated with vermiwash spray (21.50), FYM + vermicompost + panchagavya spray (21.23) and FYM + vermicompost (21.07). While, no organic manure application recorded significantly lower

Table 19. Number of leaves per plant at different growth stages of foxtail millet as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

Treatments	Number of leaves per plant								
	30 DAS			60 DAS			At harvest		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
T₁	3.40	3.67	3.53	17.11	18.81	17.96	15.35	17.33	16.34
T₂	3.60	3.88	3.74	18.57	19.92	19.25	17.09	18.40	17.75
T₃	3.87	4.18	4.02	20.69	21.44	21.07	19.23	19.85	19.54
T₄	4.00	4.29	4.14	21.73	21.99	21.86	20.06	20.38	20.22
T₅	3.77	4.28	4.03	20.49	21.97	21.23	19.32	20.36	19.84
T₆	4.07	4.40	4.23	21.76	22.57	22.16	20.43	20.93	20.68
T₇	3.80	4.14	3.97	20.00	21.24	20.62	19.46	19.66	19.56
T₈	4.07	4.43	4.25	22.07	22.74	22.41	21.01	21.09	21.05
T₉	3.90	4.25	4.08	21.20	21.81	21.50	19.90	20.20	20.05
T₁₀	4.10	4.47	4.29	22.44	22.93	22.68	21.44	21.28	21.36
T₁₁	4.77	5.19	4.98	25.05	26.64	25.84	23.87	24.73	24.30
S.Em ±	0.12	0.15	0.11	0.79	0.75	0.60	0.73	0.61	0.56
C. D. at 5%	0.36	0.43	0.31	2.33	2.21	1.77	2.16	1.77	1.65

DAS: Days after sowing

T₁ : No organic manure (Control)

T₂ : FYM equivalent to 100 % RDN

T₃ : FYM (50%) + Vermicompost (50%) equivalent to 100 % RDN

T₄ : FYM (50%) + Poultry manure (50%) equivalent to 100 % RDN

T₅ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₆ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₇ : **T₃** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₈ : **T₄** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₉ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₀ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₁ : Sole foxtail millet without tree component

number of leaves per plant (17.96) over all other treatments except FYM application (19.25).

At harvest, treatment consisting of sole foxtail millet with recommended organic nutrient practice without tree association recorded significantly higher number of leaves per plant (24.30) over the different treatments with tree component (16.34 to 24.30). The next best treatment with tree combination was FYM + poultry manure + panchagavya alternated with vermiwash spray (21.36) which recorded significantly higher number of leaves per plant when compared with no organic manurial treatment (16.34), FYM (17.75), FYM + vermicompost (19.54), FYM + vermicompost + panchagavya spray (19.84) and FYM + vermicompost + vermiwash spray (19.56). Other rest of the treatments was intermediary in their effect.

Maximum number of leaves per plant with application of FYM + poultry manure and FYM + vermicompost along with foliar spray of panchagavya and vermiwash alone and in alternate application might be due to the adequate availability and supply of nutrients in balanced proportion through soil and foliage, which ultimately resulted in triggering the production of plant growth hormones *viz.*, IAA and GA. Similar findings were also observed by Yadav and Lourdraj (2006) and Siddaram (2009).

4.4.1.3 Number of tillers per plant (cf. Table 20)

Number of tillers increased with age of crop and revealed significant variations due to organic nutrient management practices in *Melia dubia* based agroforestry system. Different organic nutrient management practices exhibited significant difference in number of tillers per plant at 60 DAS and at harvest.

At 60 DAS, in pooled data, significantly higher number of tillers per plant was recorded under sole foxtail millet with organic nutrient management practices without tree component (4.23) when compared to the treatments in agroforestry system (1.90 to 3.80). In agroforestry system, FYM + poultry manure + panchagavya alternated with vermiwash spray recorded significantly higher number of tillers per plant (3.80) than no organic manurial treatment (1.90), FYM (2.43), FYM + vermicompost (2.73), FYM + vermicompost + panchagavya spray (2.87) and FYM + vermicompost + vermiwash spray (3.28) which in turn on par with each other.

Table 20. Number of tillers per plant at different growth stages of foxtail millet as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

Treatments	Number of tillers plant ⁻¹					
	60 DAS			At harvest		
	2018	2019	Pooled	2018	2019	Pooled
T₁	1.73	2.07	1.90	2.17	2.71	2.44
T₂	2.33	2.53	2.43	2.92	3.22	3.07
T₃	2.53	2.93	2.73	3.17	3.42	3.29
T₄	3.20	3.60	3.40	3.97	4.37	4.17
T₅	2.53	3.20	2.87	3.17	4.06	3.62
T₆	3.20	3.80	3.50	4.00	4.40	4.20
T₇	3.03	3.53	3.28	3.75	4.25	4.00
T₈	3.27	4.00	3.63	4.17	4.64	4.40
T₉	3.00	3.93	3.47	3.93	4.58	4.25
T₁₀	3.53	4.07	3.80	4.33	4.74	4.54
T₁₁	4.20	4.27	4.23	4.73	5.73	5.23
S.Em ±	0.15	0.17	0.13	0.15	0.16	0.14
C. D. at 5%	0.44	0.49	0.40	0.45	0.48	0.41

DAS: Days after sowing

T₁ : No organic manure (Control)

T₂ : FYM equivalent to 100 % RDN

T₃ : FYM (50%) + Vermicompost (50%) equivalent to 100 % RDN

T₄ : FYM (50%) + Poultry manure (50%) equivalent to 100 % RDN

T₅ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₆ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₇ : **T₃** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₈ : **T₄** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₉ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₀ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₁ : Sole foxtail millet without tree component

At harvest, in pooled data, significantly higher number of tillers per plant was recorded under sole foxtail millet without tree component with organic nutrient management practices (5.23) when compared to all other treatments in agroforestry system (2.44 to 4.54). Among the treatments with agroforestry system, FYM + poultry manure + panchagavya alternated with vermiwash spray produced significantly higher number of tillers per plant (4.54) over all the treatments except FYM + poultry manure + vermiwash spray (4.40), FYM + vermicompost + vermiwash (4.25), FYM + poultry manure + panchagavya (4.20) and FYM + poultry manure (4.17) which in turn were comparable with each other. No organic manurial treatment exhibited significantly lower number of tillers per plant (2.44) than all other rest of the treatments. Application of no organic manures, FYM and FYM + vermicompost resulted in significantly lower number of tillers per plant when compared to their application along with foliar spray of panchagavya and vermiwash alone or in alternate sprays.

The higher number of tillers in sole crop with recommended nutrient management through organics without tree component and foxtail millet under tree component with FYM + vermicompost and FYM + poultry manure along with foliar spray of panchagavya and vermiwash alone or in alternate sprays was mainly due to greater availability of nutrients that encouraged the production of more number of tillers. Similar findings were documented by Priya and Sathyamoorthi (2019) and Ullasa *et al.* (2019) who reported that release of nutrients from the organic sources at later stages of crop growth had resulted in increased number of tillers at harvest. Somsundaram and Singaram (2006) who have also reported that foliar spray of panchagavya and vermiwash enhanced the tillers production of crop since these contains macro and micro nutrients, growth hormones and biofertilizers in liquid formulations which are readily available for plant growth and development apart from presence of growth enzymes present in panchagavya which might have favoured the rapid cell division and multiplication.

4.4.1.4 Leaf area per plant (cm²) (cf. Table 21 and Fig.12)

Leaf area increased with age of the crop from 30 to 60 DAS and decreased thereafter due to initiation of senescence.

At 30 DAS, in pooled data, sole foxtail millet with recommended organic nutrient practice without tree component recorded significantly higher leaf area (64.1 cm²) over

all the treatments in *Melia dubia* based agroforestry system. Among the treatments with agroforestry system, significantly higher leaf area per plant was recorded with FYM + poultry manure + panchagavya alternated with vermiwash (58.27 cm²) when compared to the all other treatments except FYM + poultry manure + panchagavya (56.36 cm²), FYM + vermicompost + panchagavya alternated with vermiwash (55.97 cm²) and FYM+ vermicompost + vermiwash (54.98 cm²), FYM + poultry manure (58.24 cm²), FYM + poultry manure (53.93 cm²) and FYM + vermicompost + panchagavya (53.84 cm²). No organic manurial treatment recorded significantly lower leaf area per plant (40.93 cm²) over all other the treatments. Effect due to other treatments was intermediary. Similar trend was followed in both the years.

At 60 DAS, in pooled data, sole foxtail millet with recommended organic nutrient management schedule without tree association recorded significantly higher leaf area per plant (1349.16 cm²) over all the treatments in agroforestry system with *Melia dubia* tree component (683.22 to 1166.05 cm²). Among the treatments with agroforestry system, FYM + poultry manure panchagavya alternated with vermiwash spray recorded significantly higher leaf area per plant (1016.10 cm²) and showed its superiority over no organic manurial treatment (683.22 cm²), FYM (724.11 cm²), FYM + vermicompost (827.25 cm²), FYM + poultry manure (923.38 cm²), FYM + vermicompost + panchagavya (923.43 cm²), FYM + vermicompost + vermiwash (950.74 cm²).

At harvest, in pooled data, significantly higher leaf area per plant was recorded in sole foxtail millet with recommended organic nutrient practices without tree component (1112.26 cm²) when compared with organic nutrient management practices in agroforestry system (588.58 to 1062.37 cm²). In tree association, application of FYM + poultry manure + panchagavya alternated with vermiwash spray recorded significantly higher leaf area per plant (1062.37 cm²) than no organic manurial treatment (588.58 cm²), FYM (672.57 cm²), FYM + vermicompost (776.29 cm²), FYM + vermicompost + panchagavya (845.71 cm²), FYM + poultry manure (881.40 cm²) and FYM + vermicompost + vermiwash (881.69 cm²). Other treatments were intermediary in their effect.

Sole crop of foxtail millet without tree component showed higher leaf area than the crop performed with tree component as a result of better avialibility of the resources. Significant increase in leaf area in organic nutrient management practices with tree

Table 21. Leaf area per plant at different growth stages of foxtail millet as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

Treatments	Leaf area per plant (cm ²)								
	30 DAS			60 DAS			At harvest		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
T₁	37.66	44.20	40.93	641.82	724.62	683.22	571.66	605.49	588.58
T₂	43.95	47.72	45.83	658.67	789.55	724.11	654.08	691.07	672.57
T₃	49.41	51.35	50.38	749.58	904.92	827.25	724.25	828.33	776.29
T₄	53.46	54.40	53.93	858.35	988.41	923.38	848.36	914.44	881.40
T₅	50.71	56.95	53.83	814.61	1032.25	923.43	807.28	884.13	845.71
T₆	54.78	57.94	56.36	947.41	1200.57	1073.99	939.47	996.48	967.97
T₇	51.44	58.51	54.98	852.49	1048.99	950.74	865.30	898.08	881.69
T₈	56.60	59.88	58.24	937.01	1199.64	1068.33	935.69	1027.94	981.82
T₉	52.49	59.44	55.97	993.19	1188.89	1091.04	947.40	1015.85	981.63
T₁₀	56.58	59.96	58.27	1037.91	1294.20	1166.05	1016.10	1108.64	1062.37
T₁₁	64.76	63.26	64.01	1104.18	1594.13	1349.16	1072.96	1151.56	1112.26
S.Em ±	1.93	2.32	1.69	46.73	48.40	44.25	50.92	45.21	44.13
C. D. at 5%	5.69	6.85	4.97	137.85	142.77	119.32	150.20	133.36	130.18

DAS: Days after sowing

T₁ : No organic manure (Control)

T₂ : FYM equivalent to 100 % RDN

T₃ : FYM (50%) + Vermicompost (50%) equivalent to 100 % RDN

T₄ : FYM (50%) + Poultry manure (50%) equivalent to 100 % RDN

T₅ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₆ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₇ : **T₃** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₈ : **T₄** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₉ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₀ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₁ : Sole foxtail millet without tree component

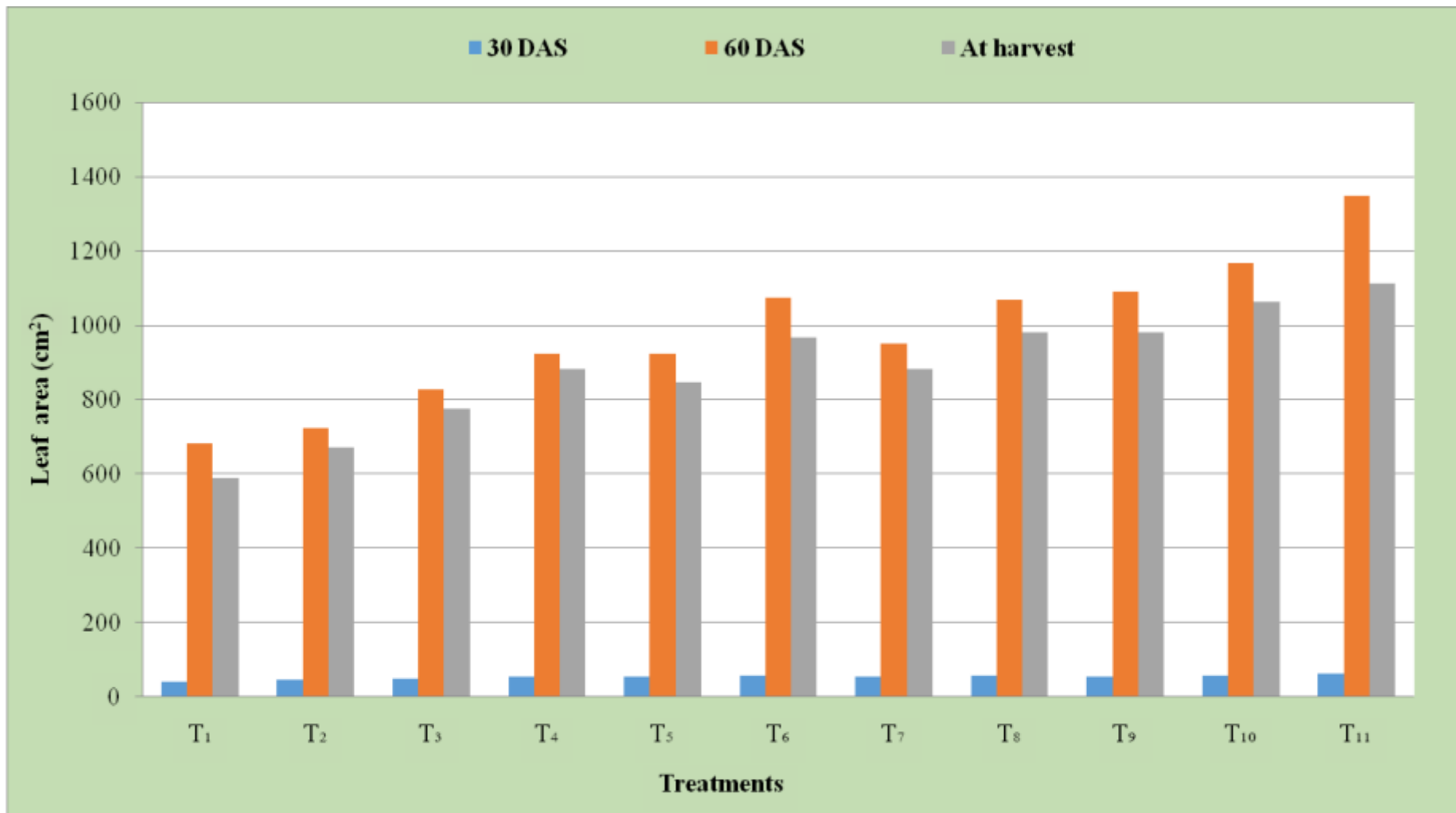


Fig. 12. Leaf area per pant at different growth stages of foxtail millet as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

component (FYM + poultry manure and FYM + vermicompost with foliar spray of panchagavya and vermiwash alone or in alternate sprays) could be attributed to the balanced and continuous supply of nutrients resulted in higher photosynthesis and translocation of photosynthates to the sink. Similar results were also observed by Divya (2012) and Pradeep Gopakkali *et al.* (2012). Panchagavya comprises coconut water which contains kinetin which might have increased the cytokinins in the leaf, as a consequence there was increase in photosynthetic activity for a longer period, hence recorded higher leaf area per plant.

4.4.1.5 Leaf area index (LAI) (cf. Table 22)

Leaf area index is the measure of source size. Significant variations were observed with respect to leaf area index at all the growth stages both in foxtail millet grown with and without tree component of *Melia dubia* in agroforestry system due to different treatments.

At 30 DAS, in pooled data, significantly higher LAI was recorded under sole foxtail millet with recommended organic nutrient management practices without tree component (0.213) when compared with treatments in agroforestry system (0.136 to 0.194). In agroforestry system, significantly higher LAI was recorded with FYM + poultry manure + panchagavya alternated with vermiwash spray (0.194) and showed its superiority over no organic manurial treatment (0.136) and FYM + vermicompost (0.153).

At 60 DAS, in pooled data, significantly higher LAI was recorded under sole foxtail millet with recommended organic nutrient management practices without tree association (4.497) when compared with treatments in agroforestry system. In agroforestry system, among the organic nutrient practices, application of FYM + poultry manure + panchagavya alternated with vermiwash recorded significantly higher LAI (3.887) over all other treatments except FYM + vermicompost + panchagavya alternated with vermiwash spray (3.637), FYM + poultry manure + panchagavya (3.580) and FYM + poultry manure + vermiwash (3.561) which in turn were comparable each other.

At harvest, in pooled data, foxtail millet with recommended organic nutrient management practice without tree association recorded significantly higher LAI (3.708) than all other treatments in foxtail millet with tree association except FYM + poultry

Table 22. Leaf area index (LAI) at different growth stages of foxtail millet as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

Treatments	Leaf area index								
	30 DAS			60 DAS			At harvest		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
T₁	0.126	0.147	0.136	2.139	2.415	2.277	1.906	2.018	1.962
T₂	0.147	0.159	0.153	2.196	2.632	2.414	2.180	2.304	2.242
T₃	0.165	0.171	0.168	2.499	3.016	2.758	2.414	2.761	2.588
T₄	0.178	0.181	0.180	2.861	3.295	3.079	2.828	3.048	2.938
T₅	0.169	0.190	0.179	2.715	3.441	3.078	2.691	2.947	2.819
T₆	0.183	0.193	0.188	3.158	4.002	3.580	3.132	3.322	3.227
T₇	0.171	0.195	0.183	2.842	3.497	3.169	2.884	2.994	2.939
T₈	0.189	0.200	0.194	3.123	3.999	3.561	3.119	3.426	3.273
T₉	0.175	0.198	0.187	3.311	3.963	3.637	3.158	3.386	3.272
T₁₀	0.189	0.200	0.194	3.460	4.314	3.887	3.387	3.695	3.541
T₁₁	0.216	0.211	0.213	3.681	5.314	4.497	3.577	3.839	3.708
S.Em ±	0.006	0.008	0.006	0.156	0.161	0.135	0.169	0.151	0.147
C. D. at 5%	0.019	0.023	0.017	0.459	0.476	0.398	0.501	0.444	0.434

DAS: Days after sowing

T₁ : No organic manure (Control)

T₂ : FYM equivalent to 100 % RDN

T₃ : FYM (50%) + Vermicompost (50%) equivalent to 100 % RDN

T₄ : FYM (50%) + Poultry manure (50%) equivalent to 100 % RDN

T₅ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₆ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₇ : **T₃** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₈ : **T₄** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₉ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₀ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₁ : Sole foxtail millet without tree component

manure + panchagavya alternated with vermiwash spray (3.541). Different organic manurial treatments exhibited significant differences in LAI of foxtail millet under agroforestry system. Application of FYM + poultry manure + panchagavya alternated with vermiwash spray recorded significantly higher LAI (3.541) over all the treatments except FYM + poultry manure + vermiwash (3.273), FYM + vermicompost + panchagavya alternated with vermiwash (3.272) and FYM + poultry manure + panchagavya (3.227), while, no organic manurial treatment recorded significantly lower LAI (1.962) than rest of the other treatments.

Higher leaf area index with application of FYM + poultry manure, FYM + vermicompost in combination with foliar spray of panchagavya and vermiwash alone or in alternate sprays may be ascribed to substantial increase in assimilatory surface area which promoted higher photosynthetic accumulates. This might also be due to better availability of nutrients and enhanced uptake of nutrients through faster rate of mineralization in soil solution through the crop growth period as a result of their combined application. Further beneficial effect of liquid manures as growth regulator substantially increased the assimilatory surface area and its function. These results were in conformity with the findings of Saunshi *et al.* (2014) and Chandana *et al.* (2018).

4.4.1.6 Dry matter production and its accumulation in different plant parts

4.4.1.6.1 Dry matter accumulation in leaves (g plant⁻¹) (cf. Table 23)

The data on dry matter accumulation in leaves differed significantly due to different treatments at different growth stages in *Melia dubia* based agroforestry during both the years and in pooled data.

At 30 DAS, during 2018 and in pooled data, FYM + poultry manure recorded significantly higher dry matter accumulation in leaves per plant (3.86 g and 3.73 g, respectively) when compared to rest of the treatments except in sole foxtail millet with recommended organic nutrient management practices without tree component (3.40 g and 3.65 g respectively). During 2019, sole foxtail millet with recommended organic nutrient schedule without tree association recorded significantly higher dry matter accumulation in leaves per plant (3.89 g) over all other treatments except FYM + poultry manure (3.60 g) and FYM + poultry manure + panchagavya alternated with vermiwash spray (3.21 g).

Table 23. Dry matter accumulation in leaves at different growth stages of foxtail millet as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

Treatments	Dry matter accumulation in leaves (g plant ⁻¹)								
	30 DAS			60 DAS			At harvest		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
T₁	1.87	2.78	2.33	6.09	7.19	6.64	4.20	4.06	4.13
T₂	2.17	2.45	2.31	6.52	7.70	7.11	4.48	5.04	4.76
T₃	2.44	2.76	2.60	7.89	9.31	8.60	4.85	5.46	5.15
T₄	3.86	3.60	3.73	7.44	8.78	8.11	5.17	5.82	5.50
T₅	2.74	3.10	2.92	8.14	9.61	8.87	5.45	5.79	5.62
T₆	3.41	2.80	3.11	8.65	10.21	9.43	5.97	6.72	6.34
T₇	2.04	2.31	2.17	6.17	6.83	6.50	4.96	5.67	5.32
T₈	2.48	2.80	2.64	8.32	9.81	9.07	5.74	6.45	6.09
T₉	2.58	2.92	2.75	8.59	10.13	9.36	5.92	6.63	6.27
T₁₀	2.84	3.21	3.02	9.39	11.08	10.24	6.81	7.66	7.24
T₁₁	3.40	3.89	3.65	10.85	12.80	11.82	8.15	10.95	10.07
S.Em ±	0.18	0.25	0.19	0.73	0.89	0.81	0.46	0.46	0.46
C. D. at 5%	0.54	0.73	0.57	2.16	2.64	2.39	1.37	1.36	1.36

DAS: Days after sowing

T₁ : No organic manure (Control)

T₂ : FYM equivalent to 100 % RDN

T₃ : FYM (50%) + Vermicompost (50%) equivalent to 100 % RDN

T₄ : FYM (50%) + Poultry manure (50%) equivalent to 100 % RDN

T₅ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₆ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₇ : **T₃** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₈ : **T₄** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₉ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₀ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₁ : Sole foxtail millet without tree component

At 60 DAS, in pooled data, sole foxtail millet with recommended organic nutrient management practice without tree component recorded significantly higher dry matter accumulation in leaves (11.82 g) when compared with various organic nutrient management practices in agroforestry system (6.64 to 10.24 g) except FYM + poultry manure + panchagavya alternated with vermiwash (10.24 g). Among the treatments in agroforestry system, FYM + poultry manure + panchagavya alternated with vermiwash spray resulted in significantly higher dry matter accumulation in leaves (10.24 g) over no organic manurial treatment (6.64 g), FYM (7.11g) and FYM + vermicompost + vermiwash spray (6.50 g). Others treatments were intermediary in their effect.

At harvest, in pooled data, significantly higher dry matter accumulation in leaves was observed under sole foxtail millet with recommended organic nutrient management practices without tree component (10.07 g) when compared with organic nutrient management treatments in agroforestry system (4.13 to 7.24 g). In agroforestry system, significantly higher dry matter accumulation in leaves per plant (7.24 g) was observed with application of FYM + poultry manure + panchagavya alternated with vermiwash spray when compared with no organic manurial treatment (4.13 g), FYM (4.76 g), FYM + vermicompost (5.15 g), FYM + poultry manure (5.50 g) and FYM + vermicompost + vermiwash (5.32 g).

4.4.1.6.2 Dry matter accumulation in stem (g plant⁻¹) (cf. Table 24)

The data on dry matter accumulation in stem of foxtail millet differed significantly due to various treatments in *Melia dubia* based agroforestry system.

At 30 DAS, in pooled data, sole foxtail millet with recommended organic nutrient management practice without tree combination recorded significantly higher dry matter accumulation in stem per plant (3.06 g) over all organic nutrient management treatments in agroforestry system. No significant difference in dry matter accumulation in stem per plant was noticed among the organic nutrient management practices, however, all the treatments showed their significant superiority over no organic manurial treatment.

At 60 DAS, in pooled data, sole foxtail millet with organic nutrient package without tree component recorded significantly higher dry matter accumulation in stem per plant (6.92 g) over all the treatments in agroforestry system (3.37 to 5.97 g). In tree association, application of FYM + poultry manure + panchagavya alternated with

Table 24. Dry matter accumulation in stem at different growth stages of foxtail millet as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

Treatments	Dry matter accumulation in stem (g plant ⁻¹)								
	30 DAS			60 DAS			At harvest		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
T₁	1.07	1.11	1.09	3.07	3.66	3.37	2.72	3.27	2.99
T₂	1.91	2.13	2.02	3.80	4.52	4.16	3.36	4.04	3.70
T₃	2.14	2.39	2.26	4.14	4.92	4.53	3.66	4.40	4.03
T₄	2.08	2.30	2.19	4.81	5.73	5.27	4.26	5.11	4.69
T₅	2.10	2.26	2.18	4.76	5.66	5.21	4.21	5.05	4.63
T₆	2.26	2.25	2.26	5.05	6.01	5.53	4.47	5.37	4.92
T₇	2.10	2.19	2.14	3.97	4.73	4.35	3.52	4.22	3.87
T₈	1.83	2.31	2.07	4.27	5.08	4.68	3.78	4.54	4.16
T₉	2.22	2.73	2.48	4.49	5.34	4.91	3.97	4.77	4.37
T₁₀	2.16	2.94	2.55	5.30	6.64	5.97	4.69	5.93	5.31
T₁₁	2.95	3.17	3.06	6.29	7.56	6.92	5.57	6.75	6.16
S.Em ±	0.22	0.28	0.21	0.23	0.27	0.24	0.20	0.24	0.22
C. D. at 5%	0.66	0.84	0.63	0.67	0.80	0.72	0.59	0.71	0.64

DAS: Days after sowing

T₁ : No organic manure (Control)

T₂ : FYM equivalent to 100 % RDN

T₃ : FYM (50%) + Vermicompost (50%) equivalent to 100 % RDN

T₄ : FYM (50%) + Poultry manure (50%) equivalent to 100 % RDN

T₅ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₆ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₇ : **T₃** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₈ : **T₄** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₉ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₀ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₁ : Sole foxtail millet without tree component

vermiwash spray recorded significantly higher dry matter accumulation in stem per plant (5.97 g) when compared to all the treatments except FYM + poultry manure+ panchagavya (5.53 g) and FYM + poultry manure (4.81 g). No organic manurial treatment recorded significantly lower dry matter accumulation in stem per plant (3.37 g) over all the treatments.

At harvest, in pooled data, sole foxtail millet with recommended organic nutrient schedule without tree association recorded significantly higher dry matter accumulation in stem per plant (6.16 g) when compared to all the treatments in tree association. Among the treatments in agroforestry system, application of FYM + poultry manure + panchagavya alternated with vermiwash spray recorded significantly higher dry matter accumulation in stem per plant (5.31 g) compared to all the treatments except FYM + poultry manure + panchagavya (4.92 g) and FYM + poultry manure (4.69 g) while, no organic manurial treatment recorded significantly lower dry matter in stem per plant (2.99 g) over all other treatments.

4.4.1.6.3 Dry matter accumulation in reproductive parts (g plant⁻¹) (cf. Table 25)

Dry matter accumulation in reproductive parts was significantly influenced with and without tree association of foxtail millet crop.

At 60 DAS, in pooled data, significantly higher dry matter accumulation in reproductive parts per plant (10.83 g) was recorded with sole foxtail millet with recommended organic nutrient management practice without tree component over all the treatments in agroforestry system (5.21 to 9.38 g). In agroforestry system, application of FYM + poultry manure + panchagavya alternated with vermiwash spray recorded significantly higher dry matter accumulation in reproductive parts per plant (9.38 g) when compared to all the treatments. Other treatments were intermediary in their effect. No organic manurial treatment recorded significantly lower dry matter accumulation in reproductive parts per plant (5.21 g) over all the treatments.

At harvest, in pooled data, sole foxtail millet with recommended organic nutrient management practice without tree association exhibited significantly higher dry matter accumulation in reproductive parts per plant (20.04 g) over all the treatments in agroforestry system. Among the treatments in agroforestry system, application of FYM + poultry manure + panchagavya alternated with vermiwash showed its significant

Table 25. Dry matter accumulation in reproductive parts at different growth stages of foxtail millet as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

Treatments	Dry matter accumulation in reproductive parts (g plant ⁻¹)					
	60 DAS			Harvest		
	2018	2019	Pooled	2018	2019	Pooled
T₁	5.22	5.21	5.21	9.85	9.73	9.79
T₂	6.32	7.34	6.83	11.93	13.34	12.64
T₃	6.53	8.12	7.32	12.32	14.76	13.54
T₄	6.72	8.15	7.44	12.68	14.82	13.75
T₅	6.79	7.78	7.29	12.82	14.15	13.48
T₆	7.03	8.43	7.73	13.27	15.32	14.30
T₇	6.59	7.73	7.16	12.44	14.06	13.25
T₈	6.99	8.20	7.59	13.19	14.90	14.05
T₉	7.28	8.54	7.91	13.73	15.52	14.63
T₁₀	8.64	10.13	9.38	16.30	18.42	17.36
T₁₁	10.06	11.60	10.83	18.98	21.10	20.04
S.Em ±	0.17	0.25	0.20	0.32	0.45	0.37
C. D. at 5%	0.51	0.74	0.59	0.96	1.32	1.08

DAS: Days after sowing

T₁ : No organic manure (Control)

T₂ : FYM equivalent to 100 % RDN

T₃ : FYM (50%) + Vermicompost (50%) equivalent to 100 % RDN

T₄ : FYM (50%) + Poultry manure (50%) equivalent to 100 % RDN

T₅ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₆ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₇ : **T₃** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₈ : **T₄** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₉ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₀ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₁ : Sole foxtail millet without tree component

superiority in dry matter accumulation in reproductive parts per plant (17.36 g) over all other treatments. Rest of other treatments were intermediary in their effect. No organic manure application resulted in significantly lower dry matter accumulation in reproductive parts per plant (9.79 g) than all the treatments.

4.4.1.6.4 Total dry matter production (g plant⁻¹) (cf. Table 26 and Fig. 13)

Total dry matter production increased progressively with advancement in age till maturity. Further, the variations in total dry matter production due to organic nutrient management practices revealed significant differences in *Melia dubia* based agroforestry system.

In pooled data, at 30 DAS, sole foxtail millet with recommended organic nutrient management practices without tree component recorded significantly higher total dry matter production per plant (6.71 g) when compared to all the treatments in agroforestry system in pooled data except FYM + poultry manure during 2018 and 2019 and FYM + poultry manure + panchagavya alternated with vermiwash spray during 2019. In agroforestry system, FYM + poultry manure recorded significantly higher total dry matter production per plant (5.92 g) when compared to all the treatments except FYM + poultry manure + panchagavya alternated with vermiwash spray (5.57 g), FYM + poultry manure + panchagavya spray (5.37 g) and FYM + vermicompost + panchagavya alternated with vermiwash spray (5.23 g). No organic manurial treatment recorded significantly lower total dry matter production per plant (3.41 g) as compared to all the treatments.

At 60 DAS, in pooled data, significantly higher total dry matter production per plant (29.58 g) was recorded with the treatment of sole foxtail millet with organic nutrient sources without tree association when compared to all the treatments in agroforestry system (15.22 to 25.59 g). Among the treatments in agroforestry system, FYM + poultry manure + panchagavya alternated with vermiwash recorded significantly higher dry matter production per plant (25.59 g) and was on par with FYM + poultry manure + panchagavya spray (22.69 g). Other treatments were intermediary in their effect while, no organic manures application treatment recorded significantly lower total dry matter production per plant (15.22 g) compared to all.

At harvest, in pooled data, sole foxtail millet with recommended organic nutrient management practices without tree component recorded significantly higher total dry

matter production per plant (36.26 g) when compared to all the treatments in agroforestry system (16.91 to 29.91 g). In agroforestry system, application FYM + poultry manure + panchagavya alternated with vermiwash spray exhibited significantly higher dry matter production per plant (29.91 g) when compared to all the treatments. The next best treatment was FYM + poultry manure + panchagavya spray (25.55 g) which in turn was on par with treatment FYM + vermicompost+ panchagavya alternated with vermiwash spray (25.27 g), FYM + poultry manure + vermiwash spray (24.30 g), FYM + poultry manure (23.93 g) and FYM + vermicompost + panchagavya (23.73 g). Significantly lower total dry matter production per plant was noticed in no organic manurial treatment (16.91 g) compared to all other treatments. Among only organic manurial treatment, FYM + poultry manure showed its significant superiority over FYM and FYM + vermicompost.

Total dry matter production is an important pre-requisite for higher yields, which indicated other bio-synthetic processes associated during the development sequences. At all the stages of crop growth, organic manurial treatments comprising of FYM + vermicompost and FYM + poultry manure along with foliar spray of panchagavya and vermiwash alone or in alternate sprays (T₅ to T₁₀) recorded higher total dry matter production as compared to no organic manure applied treatment and application of FYM alone. This might be due to improved soil aggregation, higher nutrient availability and enhanced soil microbial activity resulting in congenial soil condition as a result of combined application of organic manures along with foliar spray of panchagavya and vermiwash alone and in alternate sprays when compared to their individual application without panchgavaya and vermiwash. Panchagavya as foliar spray could have helped in balanced and faster availability of nutrients through foliage at all the stages. Vermiwash is coelomic fluid extraction contains several enzymes, plant growth hormones like cytokinins, gibberellins and vitamins along with macro and micro nutrients, which enhanced dry matter production. Similar findings were reported by Siddaram (2009), Jagadisha *et al.* (2017) and Ullasa *et al.* (2017). As a consequent of improved uptake of nutrients in these said treatments that has led to more vegetative growth of the plants and also dry matter production. Higher dry matter production was perhaps due to the higher dry matter accumulation in leaf, stem and reproductive parts recorded at 30 and 60 DAS and at harvest. This has provided more photosynthetically active leaf area resulting in higher dry matter accumulation. Apart from that, nitrogen might have involved in various

Table 26. Total dry matter production at different growth stages of foxtail millet as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

Treatments	Total dry matter production (g plant ⁻¹)								
	30 DAS			60 DAS			At harvest		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
T₁	2.93	3.89	3.41	14.39	16.05	15.22	16.77	17.06	16.91
T₂	4.07	4.58	4.33	16.65	19.56	18.10	19.77	22.41	21.09
T₃	4.58	5.14	4.86	18.55	22.35	20.45	20.83	24.61	22.72
T₄	5.94	5.90	5.92	18.97	22.66	20.81	22.11	25.76	23.93
T₅	4.84	5.36	5.10	19.69	23.05	21.37	22.47	24.99	23.73
T₆	5.67	5.07	5.37	20.73	24.65	22.69	23.70	27.41	25.55
T₇	4.14	4.50	4.32	16.74	19.29	18.01	20.92	23.95	22.44
T₈	4.31	5.11	4.71	19.58	23.09	21.33	22.70	25.89	24.30
T₉	4.80	5.65	5.23	20.35	24.01	22.18	23.63	26.91	25.27
T₁₀	5.00	6.15	5.57	23.33	27.86	25.59	27.80	32.01	29.91
T₁₁	6.36	7.07	6.71	27.20	31.96	29.58	33.73	38.80	36.26
S.Em ±	0.26	0.39	0.29	0.94	1.15	1.04	0.71	0.77	0.72
C. D. at 5%	0.78	1.16	0.86	2.79	3.38	3.07	2.11	2.66	2.12

DAS: Days after sowing

T₁ : No organic manure (Control)

T₂ : FYM equivalent to 100 % RDN

T₃ : FYM (50%) + Vermicompost (50%) equivalent to 100 % RDN

T₄ : FYM (50%) + Poultry manure (50%) equivalent to 100 % RDN

T₅ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₆ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₇ : **T₃** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₈ : **T₄** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₉ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₀ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₁ : Sole foxtail millet without tree component

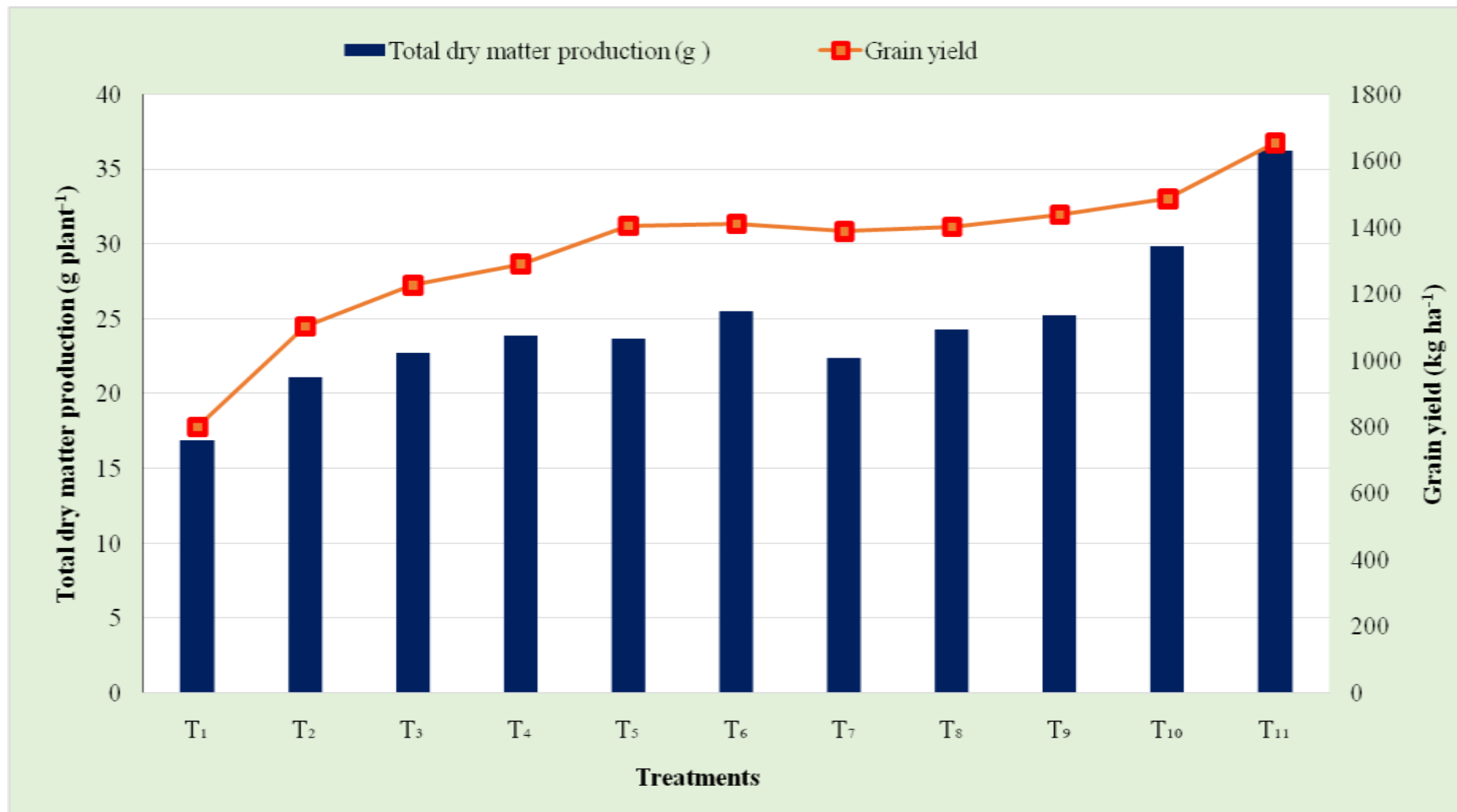


Fig. 13. Total dry matter production and grain yield of foxtail millet as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

physiological activities like increased photosynthetic activity and better light interception which in turn resulted in higher dry matter accumulation. As nitrogen could enhance tiller production and leaf area development, naturally total dry matter production also increased with different organic sources of nutrients. Similar results were also reported by Amitava *et al.* (2008) and Deshpande and Devasenapathy (2011).

4.4.1.7 Absolute growth rate (g plant⁻¹ day⁻¹) (cf. Table 27)

Absolute growth rate (AGR) differed significantly due to different nutrient sources of organics with and without tree component in both the years and pooled data at various stages of crop growth in *Melia dubia* based agroforestry system.

Between 0 and 30 DAS, in pooled data, significantly higher AGR (0.224 g plant⁻¹ day⁻¹) was recorded with sole foxtail millet with recommended organic nutrient management practices without tree component over all the treatments in tree association (0.114 to 0.197 g plant⁻¹ day⁻¹). In agroforestry system, application of FYM + poultry manure recorded significantly higher AGR (0.197 g plant⁻¹ day⁻¹) than all other treatments except FYM + poultry manure + panchagavya alternated with vermiwash spray (0.186 g plant⁻¹ day⁻¹), FYM + poultry manure + panchagavya spray (0.179 g plant⁻¹ day⁻¹) and FYM + vermicompost + panchagavya spray (0.170 g plant⁻¹ day⁻¹). No organic manurial treatment recorded significantly lower AGR value (0.114 g plant⁻¹ day⁻¹). Other treatments were intermediary in their effect.

Between 31 and 60 DAS, in pooled data, sole foxtail millet with organic nutrient sources without tree combination showed its significant superiority with respect to AGR (0.762 g plant⁻¹ day⁻¹) over rest of the treatments in tree combination except FYM + poultry manure + panchagavya alternated with vermiwash spray. Among the treatments in agroforestry system, FYM + poultry manure + panchagavya alternated with vermiwash spray recorded significantly higher AGR (0.667 g plant⁻¹ day⁻¹) when compared to all the treatments. Next best treatments were application of FYM + poultry manure + panchagavya (0.578 g plant⁻¹ day⁻¹), FYM + vermicompost + panchagavya alternated with verimwash (0.565 g plant⁻¹ day⁻¹), FYM + poultry manure + panchagavya (0.554 g plant⁻¹ day⁻¹) and FYM+ vermicompost + panchagavya (0.542 g plant⁻¹ day⁻¹) which were on par with each other. Other treatments had intermediary in their effect, while no organic manurial treatment recorded significantly lower AGR (0.394 g plant⁻¹ day⁻¹).

Table 27. Absolute growth rate (AGR) at different growth stages of foxtail millet as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

Treatments	Absolute growth rate (g plant ⁻¹ day ⁻¹)								
	0-30 DAS			31-60 DAS			61 DAS - Harvest		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
T₁	0.098	0.130	0.114	0.382	0.405	0.394	0.079	0.034	0.056
T₂	0.136	0.153	0.144	0.419	0.499	0.459	0.104	0.095	0.100
T₃	0.153	0.171	0.162	0.466	0.573	0.520	0.076	0.076	0.076
T₄	0.198	0.197	0.197	0.434	0.559	0.496	0.105	0.103	0.104
T₅	0.161	0.179	0.170	0.495	0.590	0.542	0.093	0.065	0.079
T₆	0.189	0.169	0.179	0.502	0.653	0.578	0.099	0.092	0.095
T₇	0.138	0.150	0.144	0.420	0.493	0.457	0.139	0.156	0.144
T₈	0.144	0.170	0.157	0.509	0.599	0.554	0.104	0.093	0.099
T₉	0.160	0.188	0.174	0.518	0.612	0.565	0.109	0.097	0.103
T₁₀	0.167	0.205	0.186	0.611	0.724	0.667	0.149	0.138	0.147
T₁₁	0.212	0.236	0.224	0.695	0.830	0.762	0.218	0.228	0.223
S.Em ±	0.009	0.013	0.010	0.029	0.036	0.032	0.017	0.027	0.021
C. D. at 5%	0.026	0.039	0.029	0.084	0.106	0.094	0.051	0.078	0.062

DAS: Days after sowing

T₁ : No organic manure (Control)

T₂ : FYM equivalent to 100 % RDN

T₃ : FYM (50%) + Vermicompost (50%) equivalent to 100 % RDN

T₄ : FYM (50%) + Poultry manure (50%) equivalent to 100 % RDN

T₅ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₆ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₇ : **T₃** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₈ : **T₄** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₉ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₀ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₁ : Sole foxtail millet without tree component

At 61 days to harvest, in pooled data, sole foxtail millet with recommended organic nutrient sources without tree combination recorded significantly higher AGR ($0.223 \text{ g plant}^{-1} \text{ day}^{-1}$) when compared with different organic nutrient management practices in agroforestry system. Among them, application of FYM + poultry manure + panchagavya alternated with vermiwash spray recorded significantly higher AGR ($0.147 \text{ g plant}^{-1} \text{ day}^{-1}$) compared to all the treatments except FYM + vermicompost + vermiwash spray ($0.144 \text{ g plant}^{-1} \text{ day}^{-1}$), FYM + vermicompost + panchagavya alternated with vermiwash ($0.103 \text{ g plant}^{-1} \text{ day}^{-1}$), FYM + poultry manure + vermiwash ($0.099 \text{ g plant}^{-1} \text{ day}^{-1}$) and FYM + poultry manure + panchagavya ($0.095 \text{ g plant}^{-1} \text{ day}^{-1}$) which in turn were on par with each other. Other treatments had intermediary in their effect. No organic manure treatment recorded significantly lower AGR ($0.056 \text{ g plant}^{-1} \text{ day}^{-1}$) compared to all treatments.

4.4.1.8 Crop growth rate (CGR) ($\text{g m}^{-2}\text{day}^{-1}$) (cf. Table 28)

Between 0 and 30 DAS, in pooled data, sole foxtail millet with recommended organic nutrient management practices without tree component recorded significantly higher CGR ($7.46 \text{ g m}^{-2} \text{ day}^{-1}$) when compared with different organic nutrient management treatments in agroforestry system. In agroforestry system, application of FYM + poultry manure ($6.58 \text{ g m}^{-2} \text{ day}^{-1}$) showed significant superiority over no organic manure treated plot ($3.79 \text{ g m}^{-2} \text{ day}^{-1}$), FYM ($4.81 \text{ g m}^{-2} \text{ day}^{-1}$), FYM + vermicompost ($5.40 \text{ g m}^{-2} \text{ day}^{-1}$), FYM + vermicompost + panchagavya ($5.67 \text{ g m}^{-2} \text{ day}^{-1}$) and FYM + poultry manure + panchagavya ($5.96 \text{ g m}^{-2} \text{ day}^{-1}$). Other treatments were intermediary in their effect.

Between 31 and 60 DAS, treatment comprising of sole foxtail millet without tree association with recommended organic nutrient management practices recorded significantly higher CGR ($25.41 \text{ g m}^{-2} \text{ day}^{-1}$) when compared to treatments with tree association. In agroforestry system, application of FYM + poultry manure + panchagavya alternated with vermiwash spray recorded significantly higher CGR ($22.25 \text{ g m}^{-2} \text{ day}^{-1}$) when compared to all other treatments except FYM + poultry manure + panchagavya ($16.25 \text{ g m}^{-2} \text{ day}^{-1}$). Other treatments had intermediary in their effect.

Between 61 DAS and harvest, significantly higher CGR ($7.43 \text{ g m}^{-2} \text{ day}^{-1}$) was recorded by sole foxtail millet with recommended organic management practices without tree combination when compared with different organic nutrient management practices in

Table 28. Crop growth rate (CGR) at different growth stages of foxtail millet as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

Treatments	Crop growth rate (g m ⁻² day ⁻¹)								
	0-30 DAS			31-60 DAS			61 DAS - Harvest		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
T₁	3.26	4.33	3.79	12.73	13.51	13.12	2.65	1.12	1.88
T₂	4.53	5.09	4.81	13.97	16.64	15.30	3.47	3.18	3.32
T₃	5.09	5.72	5.40	15.53	19.12	17.32	2.53	2.52	2.52
T₄	6.60	6.55	6.58	14.47	18.62	16.55	3.49	3.45	3.47
T₅	5.38	5.95	5.67	16.50	19.66	18.08	3.09	2.16	2.63
T₆	6.30	5.63	5.96	16.74	21.76	19.25	3.30	3.06	3.18
T₇	4.60	4.99	4.80	14.00	16.44	15.22	4.65	5.18	4.92
T₈	4.79	5.68	5.23	16.96	19.98	18.47	3.47	3.11	3.29
T₉	5.34	6.27	5.81	17.28	20.40	18.84	3.64	3.23	3.43
T₁₀	5.56	6.83	6.19	20.37	24.12	22.25	4.97	4.62	4.79
T₁₁	7.06	7.85	7.46	23.16	27.66	25.41	7.26	7.59	7.43
S.Em ±	0.29	0.44	0.32	0.95	1.20	1.06	0.58	0.88	0.70
C. D. at 5%	0.87	1.29	0.96	2.81	3.54	3.12	1.70	2.62	2.07

DAS: Days after sowing

T₁ : No organic manure (Control)

T₂ : FYM equivalent to 100 % RDN

T₃ : FYM (50%) + Vermicompost (50%) equivalent to 100 % RDN

T₄ : FYM (50%) + Poultry manure (50%) equivalent to 100 % RDN

T₅ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₆ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₇ : **T₃** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₈ : **T₄** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₉ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₀ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₁ : Sole foxtail millet without tree component

foxtail millet with tree association (1.88 to 4.79 g m⁻² day⁻¹). Among the treatments in agroforestry system, application of FYM + poultry manure + panchagavya alternated with vermiwash spray recorded significantly higher CGR (4.79 g m⁻² day⁻¹) compared with no organic manures treated plot (1.88 g m⁻² day⁻¹), FYM + vermiwash (2.52 g m⁻² day⁻¹) and FYM + vermicompost + panchagavya (g m⁻² day⁻¹). Other treatments had intermediary in their effect. The treatment of no organic manure application resulted in significantly lower CGR (1.88 g m⁻² day⁻¹) over all treatments except FYM (3.32 g m⁻² day⁻¹) and FYM + vermicompost + panchagavya (2.63 g m⁻² day⁻¹).

Rapid increase in crop growth rate in promising treatments after earhead formation resulted in increased accumulation of dry matter in the reproductive organs and economic sinks. As such higher CGR at all the growth stages resulted in higher total dry matter, better partitioning of dry matter, more grain and straw yield in foxtail millet. These findings are in conformity with those of Thakur *et al.* (2010) and Pallavi *et al.* (2016).

4.4.1.9 Relative growth rate (RGR) (g g⁻¹ day⁻¹) (cf. Table 29)

Relative growth rate was differed significantly due to different treatments in both the years and in pooled data at various stages of crop growth in *Melia dubia* based agroforestry system.

Between 0 and 30 DAS, in pooled data, foxtail millet without tree combination with recommended nutrient management practices registered significantly higher RGR (0.028 g g⁻¹ day⁻¹) when compared to all the treatments except FYM + poultry manure (0.026 g g⁻¹ day⁻¹) and FYM + poultry manure + panchagavya alternated with vermiwash spray (0.025 g g⁻¹ day⁻¹) with tree association. These treatments in turn showed significant superiority over no organic manural treatment (0.018 g g⁻¹ day⁻¹), FYM (0.021 g g⁻¹ day⁻¹) and FYM+ vermicompost + vermiwash (0.021 g g⁻¹ day⁻¹). While, the lower RGR was noticed with the treatment comprising of no organic manure application (0.018 g g⁻¹ day⁻¹).

Between 31 and 60 DAS, in pooled data, foxtail millet without tree association with organic nutrient sources recorded significantly higher RGR (0.047 g g⁻¹ day⁻¹) than all the treatments except FYM + poultry manure + panchagavya alternated with vermiwash spray (0.043 g g⁻¹ day⁻¹) with tree association. Later treatment in turn showed

Table 29. Relative growth rate (RGR) at different growth stages of foxtail millet as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

Treatments	Relative growth rate (g plant ⁻¹ day ⁻¹)								
	0-30 DAS			31-60 DAS			61 DAS - Harvest		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
T₁	0.016	0.020	0.018	0.024	0.030	0.027	0.022	0.025	0.023
T₂	0.020	0.022	0.021	0.032	0.039	0.035	0.029	0.032	0.030
T₃	0.022	0.024	0.023	0.034	0.042	0.038	0.031	0.035	0.033
T₄	0.026	0.025	0.026	0.037	0.045	0.041	0.033	0.037	0.035
T₅	0.023	0.024	0.024	0.036	0.044	0.040	0.032	0.036	0.034
T₆	0.025	0.023	0.024	0.037	0.046	0.042	0.034	0.038	0.036
T₇	0.020	0.022	0.021	0.032	0.039	0.036	0.029	0.032	0.031
T₈	0.021	0.023	0.022	0.036	0.044	0.040	0.032	0.036	0.034
T₉	0.023	0.025	0.024	0.035	0.043	0.039	0.032	0.035	0.034
T₁₀	0.023	0.026	0.025	0.039	0.048	0.043	0.035	0.039	0.037
T₁₁	0.027	0.028	0.028	0.042	0.051	0.047	0.038	0.042	0.040
S.Em ±	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001
C. D. at 5%	0.002	0.004	0.003	0.003	0.005	0.004	0.003	0.004	0.004

DAS: Days after sowing

T₁ : No organic manure (Control)

T₂ : FYM equivalent to 100 % RDN

T₃ : FYM (50%) + Vermicompost (50%) equivalent to 100 % RDN

T₄ : FYM (50%) + Poultry manure (50%) equivalent to 100 % RDN

T₅ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₆ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₇ : **T₃** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₈ : **T₄** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₉ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₀ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₁ : Sole foxtail millet without tree component

its significant superiority over no organic manurial treatment ($0.027 \text{ g g}^{-1} \text{ day}^{-1}$), FYM ($0.035 \text{ g g}^{-1} \text{ day}^{-1}$), FYM + vermicompost + vermiwash ($0.036 \text{ g g}^{-1} \text{ day}^{-1}$) and FYM + vermiwash ($0.038 \text{ g g}^{-1} \text{ day}^{-1}$). No organic manurial plot resulted in significantly lower RGR ($0.027 \text{ g g}^{-1} \text{ day}^{-1}$) than all the treatments.

Between 61 DAS and harvest, in pooled data, significantly higher RGR ($0.040 \text{ g g}^{-1} \text{ day}^{-1}$) was recorded with sole foxtail millet without tree component compared to all the treatments except FYM + poultry manure + panchagavya with vermiwash spray ($0.037 \text{ g g}^{-1} \text{ day}^{-1}$) and FYM + poultry manure + panchagavya ($0.036 \text{ g g}^{-1} \text{ day}^{-1}$) in agroforestry system. No organic manures plot recorded significantly lower RGR values ($0.023 \text{ g g}^{-1} \text{ day}^{-1}$) than rest of the treatments. These results are in accordance with the findings of Pallavi *et al.* (2016) and Chandana *et al.* (2020) who observed decrease in RGR values as the age of the crop.

4.4.2 Yield and yield parameters

The data related to earhead length, ear head weight, test weight, grain yield, straw yield and harvex index were presented in Table 30.

4.4.2.1 Ear head length (cm) (cf. Table 30 and Fig. 14)

In pooled data, ear head length was significantly higher with sole foxtail millet without tree component with recommended organic nutrient management schedule (26.8 cm) compared to all the treatments in *Melia dubia* based agroforestry system (16.7 to 24.30 cm).

Among the organic manurial treatments in the agroforestry system, FYM + poultry manure + panchagavya alternated with vermiwash spray showed its significant superiority (24.3 cm) over all the treatments except FYM + vermicompost + panchagavya alternated with vermiwash spray (22.9 cm), FYM+ poultry manure + panchagavya (22.8 cm) and FYM + poultry manure + vermiwash spray (22.6 cm). While, no organic manures applied plot recorded significantly lower ear head length (16.7 cm) than all the treatments.

4.4.2.2 Ear head weight (g) (cf. Table 30 and Fig. 14)

Different treatments exhibited significant differences in ear head weight of foxtail millet during both years and in pooled data in *Melia dubia* based agroforestry system.

In pooled data, sole foxtail millet without tree association with recommended organic nutrient management practices recorded significantly higher ear head weight per plant (13.68 g) over all the treatments in agroforestry system (8.94 to 12.47 g). In agroforestry system, application of FYM + poultry manure + panchagavya alternated with vermiwash spray resulted in significant higher ear head weight (12.47 g) except FYM + vermicompost + panchagavya alternated with vermiwash spray (11.83 g), FYM + poultry manure + panchagavya spray (11.60 g) and FYM + poultry manure + vermiwash spray (11.52 g). While, no organic manures application recorded significantly lower ear head weight (8.94 g) compared to all the treatments. Other treatments were intermediary in their effect. Similar trend was also followed during 2018 and 2019.

4.4.2.3 Test weight (g) (cf. Table 30 and Fig 14)

In pooled data, sole foxtail millet cultivated without tree association with recommended organic nutrient management practices recorded significantly higher test weight (3.73 g) than all treatments with tree association (2.52 to 3.19 g). In tree association, significantly higher test weight was noticed with treatment FYM + poultry manure + panchagavya alternated with vermiwash spray (3.19 g) when compared to no organic manurial treatment (2.52 g), FYM (2.65 g) and FYM + vermicompost (2.85 g). Next best treatment was FYM + vermicompost + panchagavya alternated with vermiwash (3.10 g) which was found to be on par with all other treatments except no organic manurial plot and FYM treatment. Similar trend was followed during 2018 and 2019.

Reduction in yield components in various crops under agroforestry system was reported by Peng *et al.* (2009) and Sharma *et al.* (2012). It may be attributed to availability of photosynthetically active radiation (PAR) is highly correlated with vegetative and yield attributes of the crop. Photosynthetically active radiation decreased with increase in the age of trees as reduction was 33 per cent as compared to open.

Under agroforestry system, yield parameters varied significantly due to organic nutrient management practices. This is mainly attributed to higher values of dry matter

production under respective treatments compared to their individual applications. Significant improvement in sink size could be due to increase in number of tillers, which might have resulted in development of more number of reproductive parts such as ear head length, ear head weight and the increase in sink size. Similar results were also noticed by Sujatha *et al.* (2014), Sreeja (2015), Vishwajith (2018) and Sunil Kumar *et al.* (2017). Sangeetha (2009) observed that the enhanced and continuous supply of nutrients by the organics leading to better tiller production, enhanced ear head length and test weight. Physiologically proper partitioning might have occurred from source to sink, as a result improved the yield attributes.

4.4.2.4 Grain yield (kg ha⁻¹) (cf. Table 30 and Fig. 14)

Grain yield of foxtail millet differed significantly due to various organic manurial treatments in *Melia dubia* based agroforestry system during both the years of study and in pooled data.

In pooled data, sole foxtail millet cultivation with recommended organic nutrient practices without *Melia dubia* tree component recorded significantly higher grain yield (1656 kg ha⁻¹) when compared to all other organic manurial treatments with *Melia dubia* plantation system (801 to 1487 kg ha⁻¹). In agroforestry system with *Melia dubia* plantation, application of FYM + poultry manure + panchagavya alternated with vermiwash spray resulted in significantly higher grain yield (1487 kg ha⁻¹) and it was found on par with FYM + vermicompost + panchagavya alternated with vermiwash spray (1440 kg ha⁻¹), FYM + poultry manure + panchagavya (1412 kg ha⁻¹), FYM + vermicompost + panchagavya spray (1406 kg ha⁻¹) and FYM + poultry manure + vermiwash (1403 kg ha⁻¹) which in turn were on par with each other. The next best treatment was FYM + vermicompost + vermiwash spray (1389 kg ha⁻¹), which was significantly superior over rest of the treatments. All organic manurial treatments recorded significantly higher grain yield over the treatment which received no organic manure application (801 kg ha⁻¹). The treatments receiving FYM alone and with vermicompost and poultry manure (T₂, T₃ and T₄) showed their significant inferiority with respect to recording grain yield of foxtail millet over their applications along with liquid organic manures *viz.*, panchagavya and vermiwash (T₅ to T₈). Similar results were recorded during 2018 and 2019 except FYM + vermicompost and FYM + poultry manure

with foliar spray of panchagavya and vermiwash alone or in alternate sprays with tree component (T₅ to T₁₀) were on par with each other in 2019.

4.4.2.5 Straw yield (kg ha⁻¹) (cf. Table 30)

Straw yield of foxtail millet differed significantly due to various organic manurial treatments in *Melia dubia* based agroforestry system during both the years of study and in pooled data.

In pooled data, treatments comprising of sole foxtail millet with recommended organic nutrient management practices without tree association recorded significantly higher straw yield (3127 kg ha⁻¹) over the all treatments with *Melia dubia* tree association (1637 to 2611 kg ha⁻¹). Among the organic manurial treatments in agroforestry system, FYM + poultry manure + panchagavya alternated with vermiwash spray recorded significantly higher straw yield (2611 kg ha⁻¹) over all other treatments except FYM + poultry manure + panchagavya (2545 kg ha⁻¹), FYM + vermicompost + panchagavya alternated with vermiwash spray (2511 kg ha⁻¹), FYM + poultry manure + vermiwash spray (2484 kg ha⁻¹) and FYM + vermicompost + panchagavya spray (2461 kg ha⁻¹). The treatment consisting of application of FYM + poultry manure resulted in significantly higher straw yield (2270 kg ha⁻¹) than application of FYM alone (2072 kg ha⁻¹) which inturn was on par with FYM + vermicompost (2198 kg ha⁻¹). No organic manurial treatment recorded significantly lower straw yield when compared to all the treatments in both the years and pooled data.

The pre-requisite for getting higher yield in any crop is better growth of crop which is indicated by total dry matter production and its distribution into various plant parts coupled with better translocation of photosynthates to the sink. Total dry matter production is the sum of dry matter accumulation in individual plant parts which depends on the moisture, nutrients and availability of light. The total dry matter production and its accumulation in various parts including sink influences the economic yield. The assimilation of photosynthates indicated by total dry matter production is in turn dependent on supply of adequate quantity of plant nutrients. The amount of nutrients presents in soil and their availability to synchronise with the crop demand is very much essential and decide the plant growth and yield. The economic yield which is a fraction of

the total biological yield of the crop or dry matter production is an important determinant of the grain yield.

Higher grain and straw yields with promising treatments might be resultant of higher photosynthesis and higher rate of growth as evidenced by higher values of plant height, number of tillers and leaf area per plant. As a consequence, improved uptake of nutrients has led to more vegetative growth of the plants and also dry matter production. Higher dry matter production was perhaps due to higher leaf area and higher number of tillers per plant which was recorded at all the growth stages. This has provided more photosynthetically active leaf area which resulted in higher dry matter accumulation. Apart from this, nitrogen might have involved in various physiological activities like increased photosynthetically active surface area and better light interception. Optimization of nutrients requirement of crop, especially nitrogen results in higher dry matter accumulation as evidenced by Krupashree (2019). As nitrogen could enhance number of tillers production and leaf area development, naturally total dry matter production was also increased with different organic sources.

The grain and straw yields were higher in 2019 than 2018. This is the common phenomenon in organic agriculture fields during initial years of conversion period. Some period would be required to multiply the agriculturally beneficial microorganisms in sufficient number to act upon in the soil. The mean grain yield of foxtail millet cultivated along with organic nutrient management schedule without tree component was 360 kg ha⁻¹ higher than in association with tree component, indicating 28 per cent reduction with agroforestry system. This might be due to better utilization of solar energy without any shade effect of trees in open condition. Yield reduction in foxtail millet when intercropped with *Melia dubia* compared to sole crop without trees as an intercrop was due to reduced photosynthetic active radiation on crop canopy. These results were in conformity with the findings of Anusha (2012), Divya (2013) and Pradeep (2015) in finger millet and Ashalatha *et al.* (2015) in blackgram, Bhusara *et al.* (2018) in greengram and Chandana *et al.* (2020) in pearl millet when these crops were grown with *Melia dubia* species in agroforestry system. Several workers also observed similar effect on crops when grown with tree association (Kaushik *et al.*, 2002 in pearl millet with *Dalbergia sissoo*, Dai *et al.*, 2008 in wheat and maize with *Populus deltoids*, Mutanal *et al.*, 2009 in sorghum, groundnut, chilli and finger millet with teak, Ram Pandit and Krishna Chandra

Paude, 2013 in maize and finger millet with *Ficus semicordata* and Inder *et al.*, 2017 in sesame with bamboo plantation).

The negative effect of tree on crop growth and yield of foxtail millet was reduced by application of organic nutrient management practices over a long period of time. As clearly indicated in the investigation *i.e.*, application of organic manures *i.e.*, FYM with poultry manure/vermicompost along with foliar spray of panchagavya and vermiwash alone or in alternate application (T₅ to T₁₀) resulted significantly higher yield than that noticed with no organic manurial treatment. These results were in line with findings of Bhat (2015) in *capsicum*, tomato, garden pea and cauliflower with *Melia composita* with application of vermicompost, Khan and Krishna (2016) in finger millet with *Melia azedaracha* by application of poultry manure, Pallavi *et al.* (2016) in finger millet with *Melia* species with application of poultry manure, Chandana *et al.* (2018) in pearl millet with *Melia dubia* with application of 75% RDN through poultry manure + pongamia green leaf manure @ 10 t ha⁻¹ and Kar *et al.* (2019) in garden pea with *Grewia optiva* with the use of 120% of the recommended doses of nitrogen through vermicompost and poultry manure.

Among organic manurial treatments in association with *Melia dubia* species, treatments supplemented with combination of FYM + poultry manure + panchagavya alternated with vermiwash spray (T₁₀), FYM + vermicompost + panchagavya alternated with vermiwash (T₉), FYM+ poultry manure + panchagavya (T₆), FYM + vermicompost + panchagavya (T₅) and FYM + poultry manure + vermiwash (T₈) not only resulted in on par yield but also recorded higher yield over application of no organic manures. In these treatments, higher yields with combined application of various organic manures with supplementation of liquid organic manures (Panchagavaya and vermiwash) through foliar nutrition resulted into better growth which might be due to higher yield parameters such as number of tillers, ear head length, ear head weight and test weight. Use of balanced levels of nitrogen through organic sources has optimized the availability of nutrients and helped in inducing good vegetative growth (Esakkiammal *et al.*, 2015, Divya Sahare and Babalad, 2016 and Meena *et al.*, 2010) and this resulted in more number of tillers and higher yield parameters to obtain higher yield. The increased ear head length and ear head weight noticed with the combined application of organics and liquid organic manures with these treatments (T₅, T₆, T₈, T₉ and T₁₀) may be attributed to steady supply of

nutrients which enhanced the dry matter production due to more availability of photosynthates. As a result of application of nutrients in the form of organics resulted in higher grain yield. These results are in accordance with earlier findings of Deepak *et al.* (2009), Hulihalli *et al.* (2011), Sanjay *et al.* (2016), Upendranaik *et al.* (2018), Krupashree (2019) and Priya and Sathyamoorthi (2019). Further, the combined application of various organic manures including liquid organics through foliar nutrition (T₅, T₆, T₈, T₉ and T₁₀) might have caused continuous availability of nutrients throughout the crop growth period. The treatments of organic manurial sources of nutrients showed higher concentration of available NPK nutrients in soil after harvest of crop which might be ascribed to the rapid mineralization of native and applied nutrients due to build up of microflora. Further, this consequence might also be due to presence of naturally occurring beneficial effective micro-organisms (EMO's) predominantly lactic acid bacteria, actinomycetes, bacteria and certain fungi besides beneficial and proven biofertilizers such as *Azotobactor*, *Azospirillum* and phosphobacteria and nutrients in panchagavya. Vermiwash is a rich source of vitamins, hormones, enzymes, macro and micro nutrients when applied to plants help in efficient growth. Several workers also noticed increased crop yields with integrated use of various sources of organics (Yadav and Louduraj, 2006, Deshpande and Devasenapathy, 2011, Yadav, 2013, Divya Sahare and Babalad, 2016 and Sunil Kumar *et al.*, 2017).

Treatments supplemented with combination of organic manures at recommended N levels with or without panchagavya and vermiwash (T₂, T₃, and T₄) resulted into lower grain yields among themselves compared to rest of the treatments (T₅ to T₁₀). This can be attributed due to the slow release of nutrients more or less with non-significant change from various organic nutrient sources, which might be resulted in non-availability of required nutrients during early stages thus causing set back and affected the growth.

The higher grain yield of foxtail millet in combined application of various sources of organic manures including liquid organics (T₅, T₆, T₈, T₉ and T₁₀) seemed to be the cumulative effect of yield attributes which was boosted by balanced nutrients supply. Similar results were also reported by Upendranaik *et al.* (2018) and Krupashree (2019). Increased grain yield might also be due to the increased photosynthetic activity which resulted in higher accumulation of photosynthates and translocation to sink due to better source and sink channel which resulted in higher grain yield. The variation in yield is

Table 30. Yield and yield parameters of foxtail millet as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

Treatments	Ear head length (cm)			Ear head weight (g plant ⁻¹)			Test weight (g)			Grain yield (Kg ha ⁻¹)			Straw yield (Kg ha ⁻¹)			Harvest index (%)		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
T₁	15.8	17.6	16.7	8.85	9.03	8.94	2.45	2.58	2.52	787	815	801	1558	1715	1637	33.48	32.19	32.84
T₂	19.1	19.8	19.4	9.93	10.13	10.03	2.57	2.74	2.65	1072	1136	1104	1960	2183	2072	35.34	34.22	34.78
T₃	19.8	20.5	20.1	10.32	10.50	10.41	2.80	2.90	2.85	1183	1271	1227	2017	2379	2198	36.93	34.83	35.88
T₄	20.5	21.2	20.9	10.68	10.87	10.78	2.85	3.01	2.93	1228	1354	1291	2118	2421	2270	36.71	35.88	36.29
T₅	21.1	21.3	21.2	10.82	10.93	10.88	2.97	2.93	2.95	1366	1447	1406	2233	2688	2461	37.96	35.01	36.48
T₆	22.0	23.6	22.8	11.27	11.93	11.60	3.03	3.18	3.11	1369	1455	1412	2309	2780	2545	37.27	34.37	35.82
T₇	20.1	21.1	20.6	10.44	10.83	10.64	2.87	2.98	2.93	1299	1479	1389	2252	2551	2402	36.61	36.82	36.72
T₈	22.1	23.1	22.6	11.19	11.85	11.52	2.93	3.12	3.03	1342	1464	1403	2345	2623	2484	36.44	35.82	36.13
T₉	22.5	23.3	22.9	11.73	11.93	11.83	3.03	3.17	3.10	1395	1486	1440	2355	2667	2511	37.19	35.84	36.51
T₁₀	23.9	24.7	24.3	12.30	12.64	12.47	3.13	3.25	3.19	1447	1528	1487	2394	2828	2611	37.69	35.08	36.39
T₁₁	26.2	27.3	26.8	13.35	14.01	13.68	3.63	3.82	3.73	1617	1695	1656	3008	3246	3127	35.00	34.29	34.64
S.Em ±	0.69	0.66	0.61	0.34	0.35	0.33	0.10	0.11	0.09	41	40	31	77	85	64	0.95	0.89	0.76
C.D. at 5%	2.03	1.96	1.80	1.01	1.02	0.97	0.31	0.31	0.28	121	118	90	227	252	188	NS	NS	NS

DAS: Days after sowing

NS: Non significant

T₁ : No organic manure (Control)

T₂ : FYM equivalent to 100 % RDN

T₃ : FYM (50%) + Vermicompost (50%) equivalent to 100 % RDN

T₄ : FYM (50%) + Poultry manure (50%) equivalent to 100 % RDN

T₅ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₆ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₇ : **T₃** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₈ : **T₄** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₉ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₀ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₁ : Sole foxtail millet without tree component

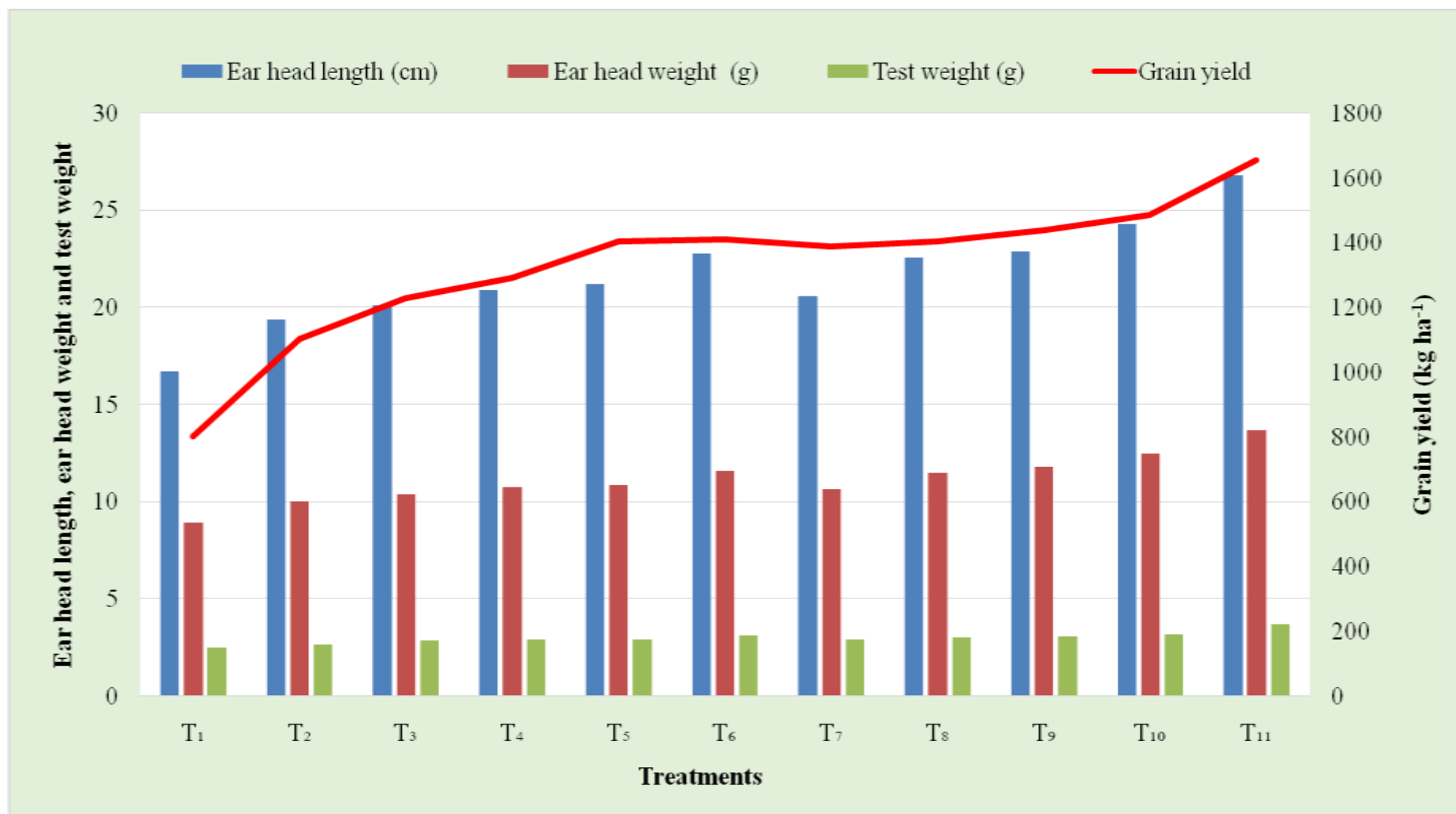


Fig. 14. Ear head length, ear head weight, test weight and grain yield of foxtail millet as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

attributed to improved growth and earhead characters that increased availability and absorption of nitrogen from soil which enhanced metabolic activities, translocation and synthesis of nutrients resulted in higher grain yield. The easy availability of nitrogen due to mineralization of organics there by influence the shoot and root growth favouring absorption of other nutrients. Similar results were obtained by and Jagadisha *et al.* (2017) and Pallavi (2019).

Significant increase in straw yield with organic nutrient management practices was attributed to build up of humus, organic carbon which improves the soil properties and increased availability of nutrients with addition of manures. These results are in line with the findings of Kumaran and Parasuraman (2019). Higher straw yield under organic manurial sources (T₅, T₆, T₈, T₉ and T₁₀) were due to higher plant height, leaf area, dry matter accumulation, more nutrient availability and uptake. These results are in conformity with the results of Patil *et al.* (2012). An increase in uptake of plant nutrients empowered the plant to manufacture more quantity of photosynthates resulting in more stover yield. Similar results were reported by Vishwajith (2018) and Krupashree (2019).

4.4.2.6 Harvest index (%)

Harvest index did not differ significantly due to organic nutrient management practices in *Melia dubia* based agroforestry system during both the years of study and in pooled basis as well. Among the organic nutrient management practices, higher harvest index was noticed with FYM + vermicompost + vermiwash (36.72 %) followed by FYM + vermicompost + panchagavya alternated with vermiwash spray (36.51 %), FYM + vermiwash + panchagavya spray (36.48 %) and FYM + poultry manure + panchagavya alternated with vermiwash spray (36.39 %) when compared with all the treatments. Other treatments were intermediary in their effect, while no organic manurial treatment had lowest harvest index (32.84 %).

4.4.3 Uptake of NPK nutrients

4.4.3.1 Uptake of nitrogen at harvest (cf. Table 31 and Fig. 15)

Different treatments in *Melia dubia* based agroforestry system exerted significant variation in uptake of nitrogen (N) by foxtail millet in both years and in pooled data.

In pooled data, sole foxtail millet without tree component with recommended organic nutrient schedule recorded significantly higher nitrogen uptake (45.67 kg ha^{-1}) when compared with all other treatments in agroforestry system except FYM + poultry manure + panchagavya alternated with vermiwash spray (40.92 kg ha^{-1}) which in turn showed its significant superiority over all the treatments except FYM + vermicompost + panchagavya alternated with vermiwash spray (38.47 kg ha^{-1}) and FYM + poultry manure + panchagavya spray (38.42 kg ha^{-1}), FYM + poultry manure (37.55 kg ha^{-1}) and FYM + poultry manure + vermiwash (36.27 kg ha^{-1}). No organic manurial treatment recorded significantly lower nitrogen uptake when compared with all the treatments (10.55 kg ha^{-1}). Effects due to other treatments were intermediary.

4.4.3.2 Uptake of phosphorus at harvest (cf. Table 31 and Fig. 15)

In pooled data, phosphorus uptake by foxtail millet was significantly superior with sole foxtail millet with recommended organic nutrient practice without tree association (12.77 kg ha^{-1}) when compared to all other treatments with tree association (4.95 to 8.92 kg ha^{-1}). Among the treatments in agroforestry system, FYM + poultry manure + panchagavya alternated with vermiwash spray recorded significantly higher phosphorus uptake (8.92 kg ha^{-1}) compared to all the treatments except FYM + poultry manure + panchagavya spray (8.73 kg ha^{-1}), FYM + poultry manure + vermiwash spray (8.58 kg ha^{-1}), FYM + vermicompost+ panchagavya alternated with vermiwash spray (8.42 kg ha^{-1}) and FYM + poultry manure (8.25 kg ha^{-1}). No organic manurial treatment recorded significantly lower phosphorus uptake (4.95 kg ha^{-1}) compared to all the treatments.

4.4.3.3 Uptake of potassium at harvest (cf. Table 31 and Fig. 15)

In pooled data, significantly higher uptake of potassium by the crop was noticed with the treatments of sole foxtail millet with recommended organic nutrient schedule without tree component (55.90 kg ha^{-1}) over all the treatments in tree association except treatment FYM + poultry manure + panchagavya alternated with vermiwash spray (44.17 kg ha^{-1}) during 2019. In agroforestry system, during 2019 and in pooled data, significantly higher potassium uptake was observed with application of FYM + poultry manure + panchagavya alternated with vermiwash spray (47.07 kg ha^{-1} and 44.17 kg ha^{-1} , respectively) when compared with potassium uptake in treatments with no organic manurial application (19.33 kg ha^{-1} and 22.18 kg ha^{-1} , respectively), FYM (27.87 kg ha^{-1}

and 26.60 kg ha⁻¹, respectively), FYM + vermicompost (33.20 kg ha⁻¹ and 32.40 kg ha⁻¹, respectively), FYM + vermicompost + panchagavya spray (31.60 kg ha⁻¹ and 32.07 kg ha⁻¹, respectively). During 2018, application of FYM + vermicompost + panchagavya alternated with vermiwash spray resulted in significantly higher potassium uptake (43.50 kg ha⁻¹) when compared to all other treatments except treatment FYM + poultry manure + panchagavya alternated with vermiwash spray (41.27 kg ha⁻¹). During both the years, lower uptake of potassium was recorded with no organic manurial treatment.

In the present study, among organic manurial treatments with association of *Melia dubia* species, uptake of nitrogen, phosphorous and potassium at harvest was higher with FYM + poultry manure + panchagavya alternated with vermiwash, FYM + vermicompost + panchagavya alteredated with vermiwash, FYM + poultry manure + panchagavya, FYM+vermiwash+panchagavya, FYM+ vermicompost+ panchagavya, when compared to other organic manurial treatments (T₂, T₃ and T₄) and no organic manurial treatment (T₁) in pooled data. It might be due to higher grain yield besides higher availability of soil nutrients in these treatments.

Increased availability of nutrients were also due to buildup of soil micro flora resulting in increased bacteria, fungi, actinomycetes, P-solubilizer and N fixer population in the soil which inturn resulted in faster decomposition of applied organic manures and caused in release of nutrients to unavailable form to available form. These results are in conformity with the findings of Sujatha *et al.* (2014).

In agroforestry system, significant increase in uptake of NPK than control was mainly due to following organic nutrient management practices. Similar findings were also reported by Khan and Krishna (2016) in finger millet and foxtail millet with *Melia azedaracha* due to application of poultry manure, Chandana *et al.* (2018) in pearl millet with *Melia dubia* due to application of 75% RDN through poultry manure + pongamia green leaf manure @ 10 t ha⁻¹ and Kar *et al.* (2019) in garden pea with *Grewia optiva* due to use of 120 per cent of the recommended doses of nitrogen through vermicompost and poultry manure.

Table 31. Uptake of nitrogen, phosphorous and potassium in foxtail millet as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

Treatments	Uptake of nutrients (Kg ha ⁻¹)								
	Nitrogen			Phosphorus			Potassium		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
T₁	9.60	11.50	10.55	4.83	5.07	4.95	25.03	19.33	22.18
T₂	26.93	27.57	27.25	6.63	6.93	6.78	25.33	27.87	26.60
T₃	32.37	37.90	35.13	7.13	7.23	7.18	31.60	33.20	32.40
T₄	34.30	40.80	37.55	8.27	8.23	8.25	32.77	34.90	33.83
T₅	30.73	36.07	33.40	6.57	6.97	6.77	31.80	36.87	34.33
T₆	35.47	41.37	38.42	8.43	9.03	8.73	32.50	39.00	35.75
T₇	31.97	37.03	34.50	7.63	7.70	7.67	32.53	31.60	32.07
T₈	33.53	39.00	36.27	8.33	8.83	8.58	37.60	35.23	36.42
T₉	34.73	42.20	38.47	8.07	8.77	8.42	42.80	36.43	39.62
T₁₀	36.40	45.43	40.92	8.77	9.07	8.92	41.27	47.07	44.17
T₁₁	40.33	51.00	45.67	12.10	13.43	12.77	54.93	56.87	55.90
S.Em ±	1.29	2.30	1.71	0.29	0.36	0.28	1.86	4.39	2.82
C. D. at 5%	3.80	6.77	5.04	0.86	1.05	0.82	5.50	12.95	8.32

DAS: Days after sowing

T₁ : No organic manure (Control)

T₂ : FYM equivalent to 100 % RDN

T₃ : FYM (50%) + Vermicompost (50%) equivalent to 100 % RDN

T₄ : FYM (50%) + Poultry manure (50%) equivalent to 100 % RDN

T₅ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₆ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₇ : **T₃** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₈ : **T₄** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₉ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₀ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₁ : Sole foxtail millet without tree component

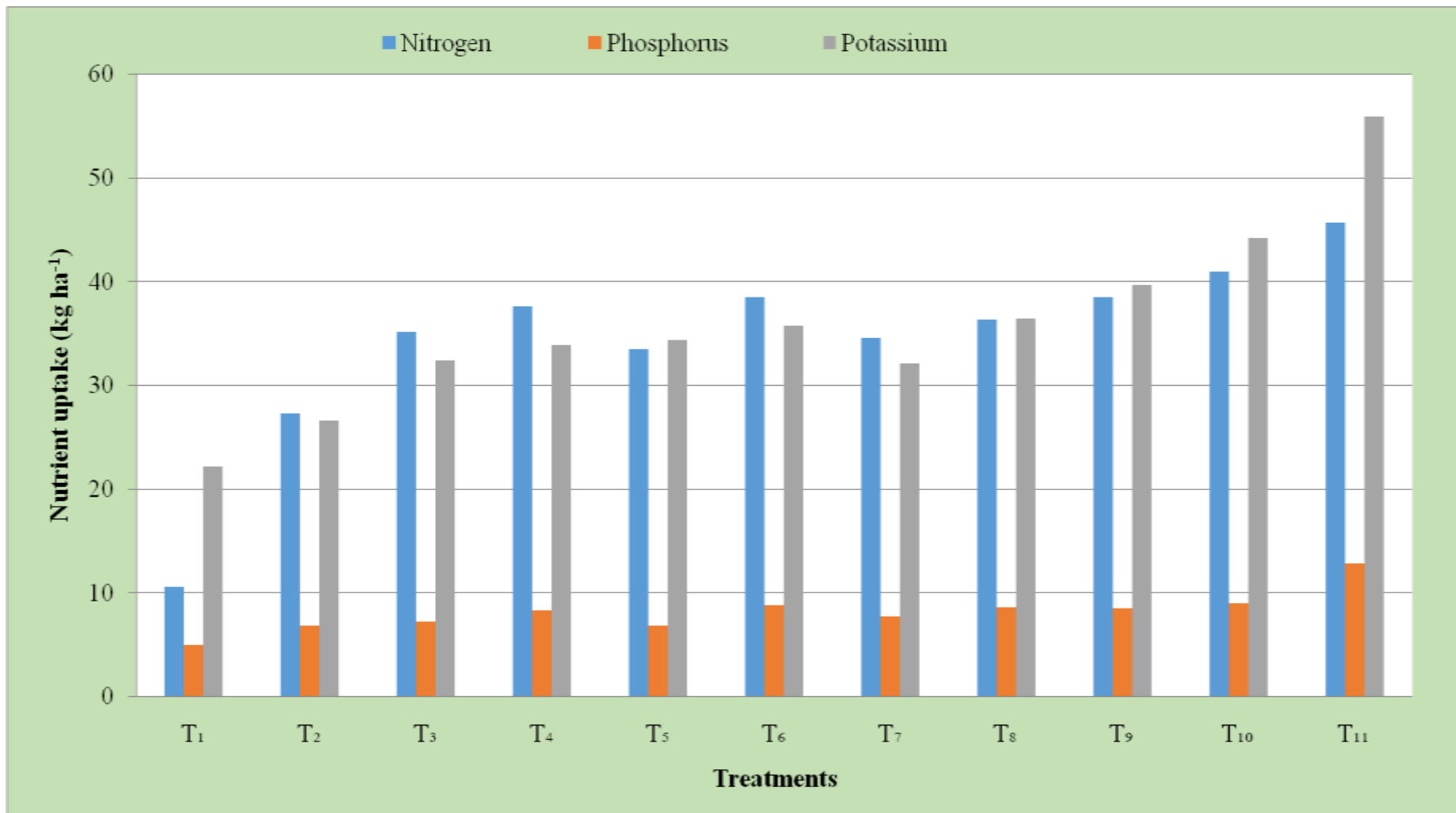


Fig. 15. Uptake of NPK nutrients by foxtail millet crop as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

4.4.4 Soil properties

4.4.4.1 Soil physico-chemical properties

4.4.4.1.1 Soil reaction (pH) (cf. Table 32)

The soil pH did not vary significantly due to different treatments in *Melia dubia* based agroforestry system during both years and in pooled data, however, there was least reduction in pH due to different organic nutrient management practices in agroforestry system, which was ranged from 7.57 to 7.60 in pooled data. Similar trend was followed in both the years of study. Reduction in soil pH in agroforestry system was attributed to release of organic acids by tree litter and applied organic inputs. Similar results were also observed by Burman *et al.* (2009), Rai *et al.* (2009), Nandal and Kumar (2010), Anusha (2012), Bhardwaj *et al.* (2017) and Patel *et al.* (2018). Moreno and Obrador (2007), Zouheir and Chaib (2011) and Muktar *et al.* (2018) reported that there was no significant difference in soil pH between crops in open condition and with tree association.

4.4.4.1.2 Electric conductivity of soil (dS m⁻¹) (cf. Table 32)

Different treatments did not exert significant variation in electric conductivity of soil with and without tree component. However, least increase in EC due to organic nutrient management treatments in agroforestry system and in sole foxtail millet without tree component was seen when compared with no organic manurial treatment in both the years of study and in pooled data.

Similar results were also observed by Bhardwaj *et al.* (2017) who reported that increase in EC among the agroforestry system compared to initial values. Bhat (2015) observed that higher doses of organic manures (vermicompst and FYM) were more effective in increasing EC when compared to no organic manure application in vegetables intercropped with *Melia composita* and without tree interface.

4.4.4.1.3 Organic carbon content of soil (cf. Table 32)

Organic carbon content of soil did not vary significantly due to different treatments with and without tree association in both the years of study and pooled analysis. Maximum organic carbon was observed with FYM + poultry manure +

Table 32. Soil pH, EC and organic carbon in foxtail millet cultivation as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

Treatments	Soil pH			Electric conductivity (dS m ⁻¹)			Organic carbon (%)		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
T₁	7.61	7.61	7.61	0.24	0.25	0.25	0.42	0.43	0.42
T₂	7.60	7.60	7.60	0.24	0.26	0.25	0.43	0.44	0.43
T₃	7.59	7.58	7.59	0.24	0.26	0.25	0.43	0.44	0.44
T₄	7.58	7.56	7.57	0.25	0.26	0.25	0.44	0.45	0.44
T₅	7.60	7.59	7.60	0.26	0.25	0.25	0.43	0.44	0.44
T₆	7.59	7.55	7.57	0.25	0.25	0.25	0.45	0.46	0.45
T₇	7.60	7.59	7.59	0.24	0.25	0.25	0.43	0.44	0.44
T₈	7.59	7.57	7.58	0.25	0.25	0.25	0.45	0.46	0.45
T₉	7.59	7.59	7.59	0.25	0.26	0.25	0.45	0.46	0.46
T₁₀	7.58	7.57	7.58	0.26	0.27	0.26	0.45	0.46	0.46
T₁₁	7.60	7.62	7.61	0.26	0.27	0.26	0.44	0.45	0.45
S.Em ±	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C. D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS

DAS: Days after sowing

NS: Not Significant

T₁ : No organic manure (Control)

T₂ : FYM equivalent to 100 % RDN

T₃ : FYM (50%) + Vermicompost (50%) equivalent to 100 % RDN

T₄ : FYM (50%) + Poultry manure (50%) equivalent to 100 % RDN

T₅ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₆ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₇ : **T₃** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₈ : **T₄** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₉ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₀ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₁ : Sole foxtail millet without tree component

panchagavya alternated with vermiwash spray (0.46 %) and FYM + vermicompost + panchagavya alternated with vermiwash spray (0.46 %). No organic manurial treatment recorded lowest organic carbon content of soil (0.42 %) when compared with all the treatments. Similar results were also reported by Odunze *et al.* (2008), Avinash *et al.* (2013), Bhat (2015), Khan and Krishna (2016) and Chandana *et al.* (2018).

4.4.4.1.4 Available soil nitrogen (kg ha⁻¹) at harvest (cf. Table 33 and Fig.16)

Soil available nitrogen differed significantly due to different treatments in *Melia dubia* with tree association during both the years and in pooled data. In pooled data, significantly higher available soil nitrogen was recorded with the FYM + poultry manure + panchagavya alternated with vermiwash spray (242.80 kg ha⁻¹) over all other treatments except FYM + poultry manure + vermiwash spray (235.17 kg ha⁻¹) which was found to be superior over rest of the treatments except FYM + poultry manure (233.50 kg ha⁻¹), FYM + vermicompost + panchagavya alternated with vermiwash spray (232.37 kg ha⁻¹) and FYM + poultry manure + panchagavya spray (232.25 kg ha⁻¹) which in turn they were comparable with each other. The treatment with no organic manures application showed significantly lower available soil nitrogen (198.53 kg ha⁻¹) and was found on par with FYM + vermicompost + vermiwash (205.38 kg ha⁻¹) and also sole foxtail millet with recommended nutrient practice without tree component (203.34 kg ha⁻¹). Significantly higher soil available nitrogen in organic manurial treatments (T₅ to T₁₀) may be attributed to rapid mineralisation of organic manures by higher microbial activity, which provided readily available nutrients to plants.

4.4.4.1.5 Available soil phosphorus (kg ha⁻¹) (cf. Table 33 and Fig. 16)

Among organic manurial treatments with tree association, in pooled data, significantly higher soil phosphorus was influenced by FYM + poultry manure + panchagavya alternated with vermiwash spray (27.60 kg ha⁻¹) when compared with no organic manurial treatment (8.55 kg ha⁻¹), FYM (20.84 kg ha⁻¹), FYM + vermicompost + panchagavya spray (22.05 kg ha⁻¹), FYM + vermicompost + vermiwash spray (23.52 kg ha⁻¹) and FYM + vermicompost (23.69 kg ha⁻¹). The next best treatment was application of FYM + poultry manure + panchagavya spray (25.65 kg ha⁻¹). The soil phosphorus in sole foxtail millet with recommended nutrient schedule without tree component was

found to be lower than all other treatments, while no organic manurial treatment in tree association resulted in significantly lower available phosphorous (8.55 kg ha^{-1}).

4.4.4.1.6 Available soil potassium (kg ha^{-1}) (cf. Table 33 and Fig. 16)

In *Melia dubia* based agroforestry system, among organic nutrient management treatments, application of FYM + poultry manure + panchagavya alternated with vermiwash spray showed its significant superiority in higher soil potassium ($311.52 \text{ kg ha}^{-1}$) when compared to all other treatments in pooled data. The next best treatment was application of FYM + poultry manure + vermiwash spray ($288.61 \text{ kg ha}^{-1}$) which in turn found to be superior over no organic manurial treatment ($187.21 \text{ kg ha}^{-1}$) and FYM ($275.04 \text{ kg ha}^{-1}$). Potassium availability in soil after harvest of crop was found to be significantly lower in sole foxtail millet with recommended organic nutrient sources without tree component than all other treatments. No organic manurial treatment recorded significantly lower available potassium in soil ($187.21 \text{ kg ha}^{-1}$). Other treatments were intermediary in their effect on available potassium in the soil. Similar trend was followed during 2018 and 2019.

Significant increase in soil available NPK due to organic manurial treatments (T₅ to T₁₀) in agroforestry system was mainly attributed to significant increase in soil beneficial micro-organisms and enzyme activities like phosphatase and dehydrogenase as observed in the present investigation. The significant increase in availability of potassium may be ascribed to the higher mineralization of K_2O by microflora in soil solution in case of combined application of organic manures and panchagavya and/or vermiwash. The increase in potassium might be due to release of potassium from mineral bound K or native K. Similar report was observed by Khan and Krishna (2016) in finger millet and foxtail millet in *Melia azedarach* based agri-silvi system with application of poultry manure, Chandana *et al.* (2018) in pearl millet with *Melia dubia* with application of 75% RDN through poultry manure + pongamia green leaf manure @ 10 t ha^{-1} , Bhat (2018) in wheat-maize cropping system under poplar based agroforestry system due to application of 50 per cent FYM and 50 per cent vermicompost and Kar *et al.* (2019) in maize - wheat cropping system in *Grewia optiva* with the use of 120 per cent of the recommended doses of nitrogen through vermicompost and poultry manure.

Table 33. Soil available nutrients in foxtail millet cultivation as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

Treatments	Soil available nutrients (Kg ha ⁻¹)								
	Nitrogen			Phosphorous			Potassium		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
T₁	206.33	190.73	198.53	11.23	5.87	8.55	192.19	182.23	187.21
T₂	212.27	203.63	207.95	20.30	21.38	20.84	272.32	277.77	275.04
T₃	214.13	212.13	213.13	22.33	25.05	23.69	278.66	284.23	281.45
T₄	238.90	228.10	233.50	24.07	25.73	24.90	283.40	289.07	286.23
T₅	218.47	207.67	213.07	21.37	22.74	22.05	277.03	282.57	279.80
T₆	232.93	231.57	232.25	24.40	26.91	25.65	282.78	288.43	285.61
T₇	208.90	201.87	205.38	22.23	24.80	23.52	283.30	288.97	286.13
T₈	239.67	230.67	235.17	25.30	24.57	24.93	285.75	291.47	288.61
T₉	238.47	226.27	232.37	23.80	25.80	24.80	283.01	288.67	285.84
T₁₀	241.17	244.43	242.80	26.57	28.63	27.60	308.43	314.60	311.52
T₁₁	208.45	198.24	203.34	15.77	18.25	17.01	225.45	245.36	235.40
S.Em ±	02.42	03.81	02.78	01.30	01.50	01.21	03.61	03.44	03.47
C. D. at 5%	07.14	11.24	08.19	03.83	04.44	03.58	10.61	10.15	10.24

DAS: Days after sowing

T₁ : No organic manure (Control)

T₂ : FYM equivalent to 100 % RDN

T₃ : FYM (50%) + Vermicompost (50%) equivalent to 100 % RDN

T₄ : FYM (50%) + Poultry manure (50%) equivalent to 100 % RDN

T₅ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₆ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₇ : **T₃** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₈ : **T₄** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₉ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₀ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₁ : Sole foxtail millet without tree component

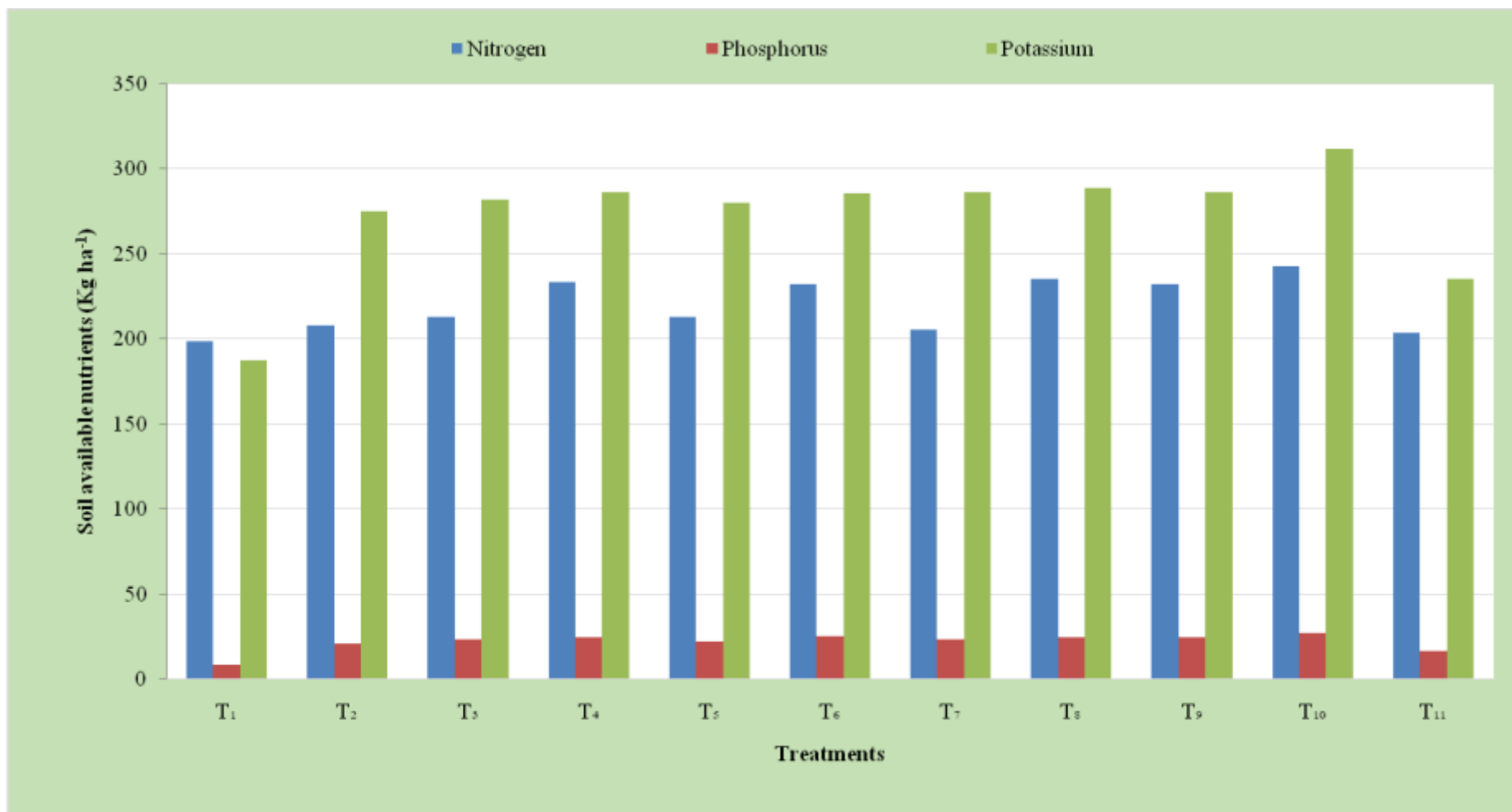


Fig. 16. Soil available nutrients (NPK) in foxtail millet cultivation as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

4.4.4.2 Soil biological properties

4.4.4.2.1 Microbial population

4.4.4.2.1.1 Bacterial population (No. x 10⁶ CFU g⁻¹ of soil) (cf. Table 34 and Fig.17)

Nutrient management practices through organics influenced soil bacterial population significantly at 60 DAS and at harvest in *Melia dubia* based agroforestry system.

At 60 DAS, in pooled data, with tree association, FYM + poultry manure + panchagavya alternated with vermiwash spray recorded significantly higher bacterial population (47.11) when compared with all the treatments except FYM + poultry manure + panchagavya spray (46.08), FYM + poultry manure + vermiwash spray (43.27), FYM + vermicompost + panchagavya alternated with vermiwash spray (43.90) and FYM + poultry manure (43.04) and also sole foxtail millet with recommended organic nutrient sources without tree component (43.80). Other treatments were intermediary in their effect. No organic manurial treatment recorded significantly lower bacterial population (28.45) over all the treatments.

At harvest, there was gradual reduction in bacterial population from 60 DAS, however, effect was followed similar trend. In both stages of crop growth, higher bacterial population was observed with organic nutrient management practices in agroforestry system when compared to without tree association.

4.4.4.2.1.2 Fungal population (No. x 10⁴ CFU g⁻¹ of soil) (cf. Table 34 and Fig. 17)

In pooled data, significant variation in fungal population in soil was exerted due to different organic nutrient management practices in foxtail millet cultivation with *Melia dubia* based agroforestry system. At 60 DAS, with tree association, application of FYM + poultry manure + panchagavya alternated with vermiwash spray resulted in significantly higher fungal population (33.80) and also sole foxtail millet with recommended organic nutrient sources without tree component (31.69) when compared with no organic manurial treatment (20.64), FYM (28.16), FYM + vermicompost + panchagavya spray (30.23).

At harvest, with tree association, application of FYM + poultry manure + panchagavya alternated with vermiwash spray recorded significantly higher fungal population (32.77) when compared with no organic manures treated plot (18.80) and FYM (26.91) and FYM + vermicompost + panchagavya (29.10).

4.4.4.2.1.3 Actinomycetes population (No. $\times 10^3$ CFU g^{-1} of soil) (cf. Table 34 and Fig. 17)

Actinomycetes population in soil was significantly influenced by different organic nutrient management practices in foxtail millet cultivation in *Melia dubia* based agroforestry system in both the years and pooled data. In pooled data, with tree association, FYM + poultry manure + panchagavya alternated with vermiwash spray recorded significantly higher actinomycetes population (35.14) when compared with no organic manurial treatment (22.18) and application of FYM (30.01) and was on par with rest of the treatments. The no organic manurial treatment resulted in significantly lower actinomycetes population (22.18).

At harvest, in pooled data, with tree association, application of FYM + poultry manure + panchagavya alternated with vermiwash spray followed by FYM + poultry manure + panchagavya spray showed their significant superiority with respect to actinomycetes population (34.95 and 33.42, respectively) when compared with no organic manurial treatment (20.10) and application of FYM alone (29.24). The actinomycetes population recorded with no organic manurial treatment was significantly lower than all other treatments.

Organic manures not only help to supply the nutrients but also act as a food for microorganisms and encourage the multiplication of their population, which in turn improves the mineralization of nutrients in soil and thus, fertility and productivity of the soil will be improved. The enhancement of soil microbial biomass is known to influence crop productivity and nutrient cycling. In the present study, with tree association, significant improvement in the population of soil micro-organisms *viz.*, bacteria, fungi and actinomycetes were with organic manurial treatments *i.e.*, noticed at 60 DAS and harvest of foxtail millet. Marked effect was more in agroforestry system than open land. This might be due to the presence of easily metabolizable compounds at the beginning of the crop and also under active growth phase on account of releasing higher amounts of

Table 34. Bacteria, fungi and actinomycetes population in soil at 60 DAS and harvest in foxtail millet cultivation as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

Treatments	Bacteria (No. × 10 ⁶ CFU g ⁻¹ of soil)						Fungi (No. × 10 ⁴ CFU g ⁻¹ of soil)						Actinomycetes (No. × 10 ³ CFU g ⁻¹ of soil)					
	60 DAS			At harvest			60 DAS			At harvest			60 DAS			At harvest		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
T₁	33.33	23.57	28.45	28.18	19.24	23.71	23.04	18.24	20.64	21.89	15.71	18.80	24.00	20.36	22.18	22.58	17.61	20.10
T₂	37.57	41.70	39.63	36.82	41.28	39.05	26.57	29.76	28.16	25.24	28.57	26.91	28.18	31.84	30.01	27.33	31.16	29.24
T₃	39.18	43.49	41.33	38.39	43.05	40.72	29.30	31.47	30.39	27.84	31.52	29.68	29.38	33.20	31.29	28.50	32.49	30.50
T₄	40.80	45.29	43.04	39.98	44.84	42.41	29.38	33.24	31.31	27.91	31.59	29.75	30.60	34.58	32.59	29.68	33.84	31.76
T₅	39.50	43.85	41.67	38.71	43.41	41.06	28.20	32.25	30.23	26.79	31.40	29.10	29.63	33.48	31.55	28.74	32.76	30.75
T₆	43.67	48.48	46.08	42.80	46.57	44.69	30.91	34.62	32.77	29.37	33.28	31.33	32.20	36.39	34.29	31.24	35.61	33.42
T₇	39.47	43.82	41.64	38.68	43.38	41.03	28.42	32.50	30.46	27.67	32.00	29.83	29.61	33.45	31.53	28.72	32.74	30.73
T₈	41.01	45.52	43.27	40.19	45.07	42.63	29.52	33.06	31.29	28.04	32.08	30.06	30.76	34.76	32.76	29.83	34.01	31.92
T₉	41.61	46.19	43.90	40.78	45.73	43.25	29.72	33.29	31.50	28.23	31.96	30.10	30.96	34.98	32.97	30.03	34.23	32.13
T₁₀	45.46	48.77	47.11	44.55	48.28	46.41	31.89	35.71	33.80	30.12	35.41	32.77	33.19	37.09	35.14	32.66	36.23	34.95
T₁₁	41.52	46.08	43.80	41.02	45.62	43.32	29.89	33.48	31.69	28.40	32.15	30.27	31.14	34.95	33.05	30.20	34.43	32.32
S.Em ±	01.61	01.92	01.71	01.67	01.90	01.70	01.16	01.28	01.19	01.01	01.38	01.12	01.25	01.41	01.32	01.26	01.47	01.35
C.D. at 5%	04.76	05.67	05.04	04.92	05.61	05.03	03.43	03.77	03.51	02.99	04.07	03.29	03.70	04.15	03.91	03.71	04.33	03.99

DAS: Days after sowing

T₁ : No organic manure (Control)

T₂ : FYM equivalent to 100 % RDN

T₃ : FYM (50%) + Vermicompost (50%) equivalent to 100 % RDN

T₄ : FYM (50%) + Poultry manure (50%) equivalent to 100 % RDN

T₅ : T₃ + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₆ : T₄ + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₇ : T₃ + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₈ : T₄ + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₉ : T₃ + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₀ : T₄ + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₁ : Sole foxtail millet without tree component

root exudates, supporting numerous and diverse micro flora. The significant increase in microbial population was observed with the addition of organic manures in combination with liquid organic manures viz., panchagavya and vermiwash in foxtail millet cultivation in *Melia dubia* based agroforestry system. Treatments which received FYM + poultry manure or FYM + vermicompost + panchagavya alternated with vermiwash recorded higher microbial population when compared with rest of the treatments. Lower microbial population was noticed in no organic manurial treatment and foxtail millet cultivation with recommended organic nutrient sources without tree association. They did not cause any significant variations in the soil microbial population, growth and functioning of soil microbial biomass as carbon substrate availability was limited. These results are in line with the findings of Meena *et al.* (2010), Govindaraju and Reddy (2011) and Alagappan *et al.* (2018) who reported higher soil microbial population with addition of combined application of organics.

When comparison made between with and without tree component, microbial population were higher in tree association than in open condition. These results are in conformity with findings of Srinivasan and Mohan (2006), Yadav *et al.* (2011), Bainard *et al.* (2013), Ramulu (2014), Balakrishna *et al.* (2016), Doddabasava *et al.* (2018), Indra *et al.* (2018) and Yengwe *et al.* (2018) in different agroforestry system than sole crops.

4.4.4.2 Enzyme activity

4.4.4.2.1 Alkaline phosphatase activity ($\mu\text{g PNP cfu g}^{-1} \text{ soil hr}^{-1}$) (cf. Table 35 & Fig.18)

Organic nutrient management practices significantly influenced alkaline phosphatase activity in soil in *Melia dubia* based agroforestry system with foxtail millet during both the years of study and pooled data. In all the treatments, the alkaline phosphatase activity exhibited highest at 60 DAS and there after the activity decreased gradually to harvest.

At 60 DAS, in pooled data, with tree association, significantly higher phosphatase activity was found with application of FYM + poultry manure + panchagavya alternated with vermiwash (124.38) when compared with no organic manurial treatment (77.95), FYM (101.42), FYM + vermicompost (110.60), FYM + vermicompost + vermiwash spray (108.70) and FYM + vermicompost + panchagavya (112.27). The alkaline

phosphatase activity recorded with foxtail millet with recommended organic nutrient sources without tree association (108.28) was significantly higher than with the tree association under no organic manurial treatment. Significantly lower alkaline phosphate activity was observed with no organic manurial treatment (72.16).

In all the treatments, the alkaline phosphatase activity decreased gradually at harvest. At harvest, significantly higher alkaline phosphatase activity was observed with application of FYM + poultry manure + panchagavya alternated with vermiwash spray (117.65) when compared with the no organic manurial treatment (77.95), FYM (95.91), FYM + vermicompost + vermiwash spray (102.95), FYM + vermicompost (104.75) and FYM + vermicompost + panchagavya (106.00). In agroforestry system, significantly lower alkaline phosphatase activity was recorded with no organic manurial treatment (72.16).

Among the various enzymes, phosphatase speeds up soil organic phosphorus decomposition and improves soil phosphorus concentration, which is an important index to assess soil phosphorus bio-availability.

4.4.4.2.2.2 Dehydrogenase activity ($\mu\text{g TPF formed g}^{-1} \text{ soil day}^{-1}$) (cf. Table 35 & Fig.18)

Dehydrogenase activity in soil was significantly influenced by different organic nutrient management practices in foxtail millet cultivation under *Melia dubia* based agroforestry system in both the years of study and in pooled data. In pooled data, at 60 DAS, with tree association, significantly higher dehydrogenase activity was noticed with application of FYM + poultry manure + panchagavya alternated with vermiwash spray (44.78) when compared with the treatments, no organic manures applicaion (26.94), FYM (37.96), FYM + vermicompost + vermiwash spray (40.13) and FYM + vermicompost + panchagavya (40.27). The dehydrogenase activity in the treatment without tree association (37.30) was found to be significantly lower than all organic manurial treatments in tree association except no organic manurial treatment.

At harvest, with tree association in agroforestry system, application of FYM + poultry manure + panchagavya alternated with vermiwash spray recorded significantly higher dehydrogenase activity (36.49) when compared with no organic manurial treatment (20.84), and FYM (30.98). Next best treatment was application of FYM +

Table 35. Alkaline phosphatase and dehydrogenase activities in soil at 60 DAS and harvest in foxtail millet cultivation as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

Treatments	Alkaline phosphatase ($\mu\text{g PNP cfu g}^{-1} \text{ soil hr}^{-1}$)						Dehydrogenase ($\mu\text{g TPF formed g}^{-1} \text{ soil day}^{-1}$)					
	60 DAS			At harvest			60 DAS			At harvest		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
T₁	82.56	73.34	77.95	78.43	65.90	72.16	31.33	22.55	26.94	24.94	16.75	20.84
T₂	96.74	106.11	101.42	91.90	99.92	95.91	35.31	40.61	37.96	28.96	33.01	30.98
T₃	105.52	115.69	110.60	100.25	109.25	104.75	38.19	43.92	41.05	31.31	35.70	33.51
T₄	112.93	123.32	118.12	107.28	115.25	111.26	38.35	44.10	41.23	31.45	35.18	33.32
T₅	107.12	117.43	112.27	101.76	110.23	106.00	37.46	43.08	40.27	30.72	35.02	32.87
T₆	114.44	125.24	119.84	108.71	118.20	113.46	39.05	45.58	42.31	32.54	37.09	34.81
T₇	103.78	113.63	108.70	98.59	107.31	102.95	37.33	42.93	40.13	31.28	34.66	32.97
T₈	112.83	123.61	118.22	107.19	116.62	111.90	38.55	44.33	41.44	31.61	35.87	33.74
T₉	112.29	123.14	117.71	106.64	115.53	111.08	38.80	44.62	41.71	31.82	36.27	34.04
T₁₀	118.78	129.99	124.38	112.84	122.47	117.65	42.73	46.84	44.78	35.04	37.94	36.49
T₁₁	103.59	112.97	108.28	98.41	107.09	102.75	38.36	36.24	37.30	31.79	32.24	32.01
S.Em\pm	2.29	2.44	2.47	2.12	2.21	1.99	01.37	01.45	01.44	01.23	01.49	01.35
C.D. at 5%	6.76	7.19	6.41	6.27	6.52	5.89	04.05	04.56	04.26	03.63	04.41	03.97

DAS: Days after sowing

T₁ : No organic manure (Control)

T₂ : FYM equivalent to 100 % RDN

T₃ : FYM (50%) + Vermicompost (50%) equivalent to 100 % RDN

T₄ : FYM (50%) + Poultry manure (50%) equivalent to 100 % RDN

T₅ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₆ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₇ : **T₃** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₈ : **T₄** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₉ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₀ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₁ : Sole foxtail millet without tree component

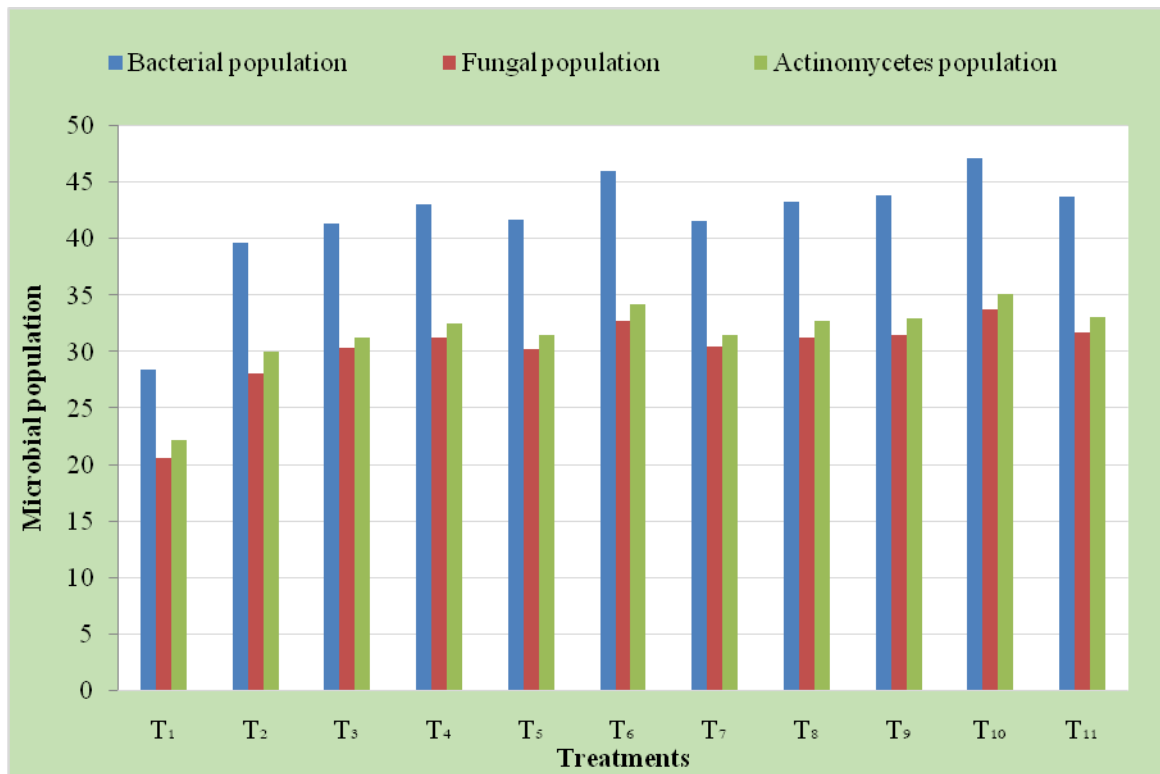


Fig. 17. Microbial population in soil as influenced by organic nutrient management practices in foxtail millet- *Melia dubia* based agroforestry system

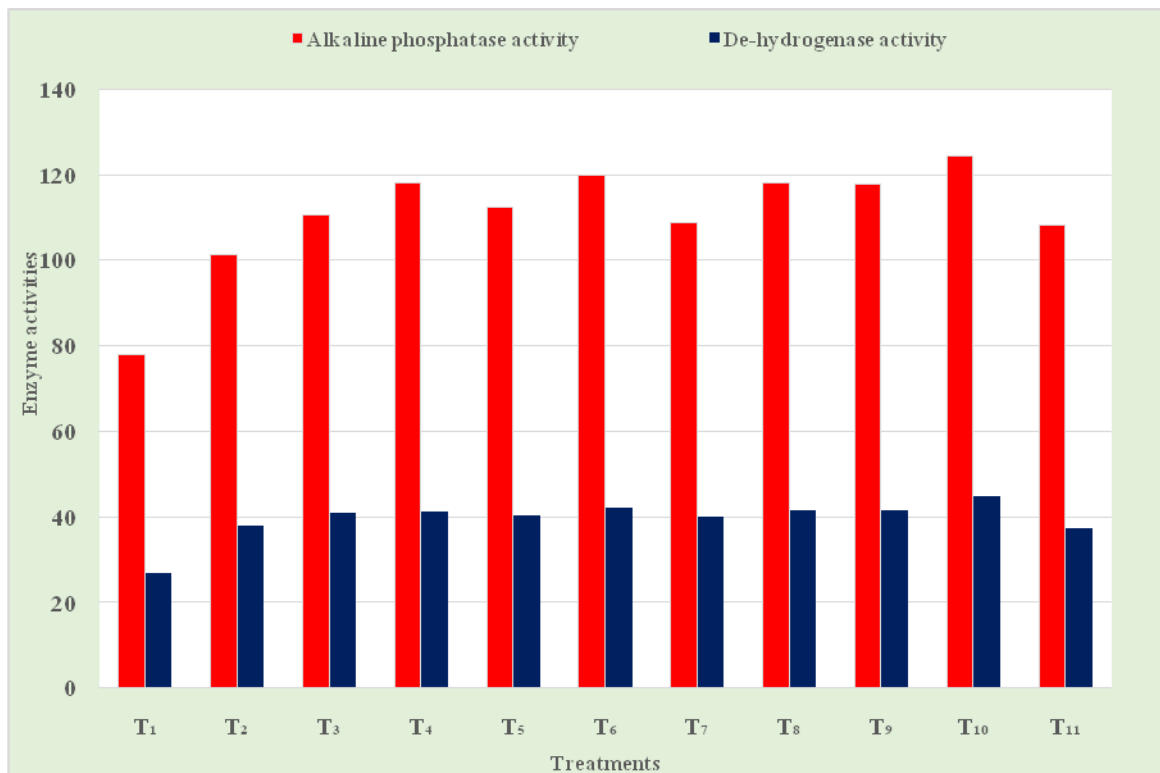


Fig. 18. Alkaline phosphatase and dehydrogenase activities in soil as influenced by organic nutrient management practices in foxtail millet- *Melia dubia* based agroforestry system

poultry manure + panchagavya spray (34.81) which showed significant superiority over no organic manurial treatment. Other treatments were intermediary in their effect. The dehydrogenase activity in the treatment of foxtail millet without tree association (32.01) was found to be lower than all organic manurial treatments in tree association except no organic manurial treatment and FYM application.

The phosphatase and dehydrogenase activity in soil is an indication of higher soil biological activity which resulted in better mineralization of nutrients. The organic manurial treatment, FYM + poultry manure and FYM +vermicompost + panchagavya alternated with vermiwash recorded significantly higher phosphatase and dehydrogenase activities in soil at 60 DAS and at harvest in foxtail millet cultivation under *Melia dubia* based agroforestry system. Higher activities of these enzymes might have resulted in greater availability of organic matter, narrow C: N ratio and favourable soil physical and chemical properties, thus leading to greater release of major and micronutrients to the crop. This has influenced on higher uptake of nutrients with these treatments and thus ultimately resulted in higher economic yield of foxtail millet. These results are in confirmation with findings of Sangeetha (2009), Divya Sahare (2012), Biradar *et al.* (2017), Purva Dubey *et al.* (2018) and Rajanand Hiremath (2018).

When comparison was made between with and without tree association, enzyme activities showed higher in tree association than without tree association. Similar effect was reported by Chander *et al.* (1998), Rajendra and Mertia (2005), Sheoran *et al.* (2018) and Yengwe *et al.* (2018) in different agroforestry systems.

4.4.5 Tree properties

Observation on various tree properties at the age of five and six years of plantation during 2018 and 2019 respectively as influenced by different organic nutrient management practices are recorded and presented below.

4.4.5.1 Tree height (m) (cf. Table 36)

Observation on tree height of *Melia dubia* was recorded at the beginning and end of the experiment during 2018 and 2019. During 2019, maximum tree height was noticed with treatment FYM + poultry manure + panchagavya alternated with vermiwash spray (13.75 m) followed by FYM + poultry manure + panchagavya spray (13.56 m) and lower tree height was recorded with no organic manurial treatment (12.13 m). During two years period of experimentation, highest increment of 5.26 per cent in tree height was noticed with treatment FYM + poultry manure followed by treatments FYM + poultry manure + panchagavya alternated with vermiwash spray and FYM + vermicompost + panchagavya alternated with vermiwash spray.

4.4.5.2 Bole height (m) (cf. Table 36)

At the end of second year of experimentation during 2019, the highest bole height of *Melia dubia* was observed with treatment FYM + poultry manure + panchagavya spray (10.45 m) and FYM + vermicompost + panchagavya alternated with vermiwash spray (10.45 m) followed by FYM + poultry manure + panchagavya alternated with vermiwash spray (10.42 m), while lower was recorded with no organic manurial treatment over all other treatments. Highest increment in bole height of 7.30 per cent was noticed with treatment FYM + poultry manure + panchagavya alternated with vermiwash spray.

4.4.5.3 Girth at breast height (cm) (cf. Table 36)

At the end of second year of experimentation during 2019, there was not much variation in tree girth at breast height (GBH) among the organic manurial treatments, however, higher GBH was observed with FYM + vermicompost + vermiwash (67.8 cm) followed by FYM + poultry manure + panchagavya (66.50 cm). The lower GBH was recorded with no organic manurial treatment (63.0 cm). Highest increment of 7.79 per cent of GBH was noticed with treatment FYM + poultry manure + panchagavya alternated with vermiwash spray.

4.4.5.4 Diameter at breast height (cm) (cf. Table 36)

At the end of second year of experimentation during 2019, higher tree diameter at breast height (DBH) was observed with application of FYM + vermicompost + vermiwash (66.8 cm) followed by application of FYM + poultry manure + panchagavya (66.50 cm).

While, lower DBH was registered with no organic manurial treatment (63.4 cm). Highest increment of 6.04 per cent in DBH was noticed with treatment FYM + poultry manure + panchagavya alternated with vermiwash spray.

Table 36. *Melia dubia* tree growth properties under organic nutrient management practices with foxtail millet intercropping system

Treatments	Tree height (m)				Bole height (m)				GBH (cm)				DBH (cm)				Collar diameter (cm)			
	Initial	2018	2019	Increment (%)	Initial	2018	2019	Increment (%)	Initial	2018	2019	Increment (%)	Initial	2018	2019	Increment (%)	Initial	2018	2019	Increment (%)
T₁	11.98	12.11	12.13	1.25	10.00	10.10	10.20	1.99	62.4	63.8	63.0	2.62	62.1	63.2	63.4	2.09	78.2	79.2	80.3	2.67
T₂	12.25	12.65	12.85	4.85	9.85	10.05	10.21	3.62	62.5	62.9	64.7	3.59	61.8	62.3	64.1	3.70	78.8	80.2	82.5	4.64
T₃	12.35	12.75	12.96	4.89	9.82	10.05	10.23	4.13	62.8	63.8	65.2	3.86	62.2	63.2	64.6	3.82	81.0	82.3	85.3	5.23
T₄	12.58	12.89	13.25	5.26	9.78	10.02	10.35	5.75	63.7	64.7	66.3	3.96	63.1	64.1	65.6	3.92	83.1	85.1	88.2	6.05
T₅	12.5	12.78	12.93	3.41	9.65	09.88	10.18	5.42	62.6	64.0	65.4	4.55	62.2	63.4	64.8	4.14	81.2	84.2	85.6	5.36
T₆	12.95	13.25	13.56	4.66	9.85	10.25	10.45	6.01	63.7	64.7	65.1	2.15	63.1	64.1	66.5	5.33	79.2	82.3	84.2	6.22
T₇	12.65	13.02	13.21	4.38	9.62	09.98	10.25	6.45	64.8	66.0	66.8	3.02	64.2	65.3	66.8	4.01	80.5	83.5	86.2	6.96
T₈	12.55	12.73	13.12	4.50	9.65	09.89	10.28	6.43	60.0	61.4	64.1	5.13	59.4	60.8	65.5	5.07	80.5	82.5	85.4	6.00
T₉	12.25	12.62	12.85	4.84	9.85	10.20	10.45	6.00	62.8	64.4	66.5	5.82	62.3	63.8	65.8	5.54	79.5	82.5	84.3	5.96
T₁₀	13.11	13.42	13.75	4.82	9.7	10.15	10.42	7.30	62.9	64.4	67.8	7.79	62.0	63.8	65.9	6.04	82.1	84.5	88.2	7.30
T₁₁	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

T₁ : No organic manure (Control)

T₂ : FYM equivalent to 100 % RDN

T₃ : FYM (50%) + Vermicompost (50%) equivalent to 100 % RDN

T₄ : FYM (50%) + Poultry manure (50%) equivalent to 100 % RDN

T₅ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₆ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₇ : **T₃** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₈ : **T₄** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₉ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₀ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₁ : Sole foxtail millet without tree component

4.4.5.5 Collar diameter (cm) (cf. Table 36)

At the end of second year of experiment during 2019, application of FYM + poultry manure + panchagavya alternated with vermiwash (88.20 cm) and FYM + poultry manure (88.19 cm) recorded higher collar diameter with marked increment in size when compared with rest of the treatments.

4.4.5.6 Canopy spread (m) (cf. Table 37)

Observation on tree canopy spread was recorded in both North – South (N - S) and East - West (E - W) directions at beginning of the experiment during 2018 and 2019. No marked effect on canopy spreading of *Melia dubia* due to different organic manurial treatments was noticed. During 2018, in N-S direction, canopy spread was ranged from 2.56 to 3.28 m and 3.25 to 3.89 m in E-W direction. During 2019, canopy spread was ranged from 2.64 to 3.38 m in N-S and 3.87 to 4.45 in E-W direction.

4.4.5.7 Light reduction percentage (cf. Table 37)

Light interception study was done in both with and without tree component. In pooled data, significantly lower light reduction percentage was recorded with sole foxtail millet with recommended organic nutrient management practices without tree component (20.98) when compared with all the treatments in agroforestry system (32.06 to 35.06).

4.4.5.8 Biomass production

4.4.5.8.1 Wood volume (t ha⁻¹) (cf. Table 38)

Melia dubia tree wood volume was recorded at the end of the experiment (2019) which ranged from 49.99 to 61.48 t ha⁻¹, the highest was recorded with application of FYM + poultry manure + panchagavya (61.48 t ha⁻¹) followed by FYM + poultry manure + panchagavya alternated with vermiwash spray (61.04 t ha⁻¹). While, no organic manurial treatment recorded the lowest wood volume (49.99 t ha⁻¹). The effect of other treatment was intermediary.

4.4.5.8.2 Above ground biomass production (t ha⁻¹) (cf. Table 38)

Observation on above ground biomass production was recorded at the end of the experiment during 2019, which ranged from 27.52 to 34.98 t ha⁻¹. Significantly higher

Table 37. *Melia dubia* tree canopy spread and light reduction percentage under organic nutrient management practices in foxtail millet - *Melia dubia* based agroforestry system

Treatments	Canopy spread (m)						Light reduction (%)		
	Initial		2018		2019		2018	2019	Pooled
	N-S	E-W	N-S	E-W	N-S	E-W			
T₁	2.85	3.55	3.28	3.73	3.38	3.95	32.39	35.64	34.01
T₂	2.72	3.44	3.13	3.61	3.22	3.87	33.43	36.70	35.06
T₃	2.75	3.40	3.16	3.57	3.26	3.95	34.38	35.54	34.96
T₄	2.72	3.25	3.13	3.41	3.22	4.15	32.10	36.89	34.49
T₅	2.74	3.48	3.15	3.65	3.25	4.10	32.58	34.87	33.72
T₆	2.71	3.36	3.12	3.53	3.21	4.28	32.10	32.76	32.43
T₇	2.78	3.59	3.20	3.67	3.29	4.11	33.62	35.06	34.34
T₈	2.45	3.58	2.82	3.72	2.90	4.02	32.20	35.54	33.87
T₉	2.23	3.62	2.56	3.69	2.64	4.39	32.39	32.85	32.62
T₁₀	2.49	3.89	2.86	4.13	2.95	4.45	32.10	36.02	34.06
T₁₁	-	-	-	-	-	-	20.74	21.23	20.98
S.Em ±	-	-	-	-	-	-	1.50	1.61	1.44
C. D. at 5%	-	-	-	-	-	-	4.42	4.74	2.44

T₁ : No organic manure (Control)

T₂ : FYM equivalent to 100 % RDN

T₃ : FYM (50%) + Vermicompost (50%) equivalent to 100 % RDN

T₄ : FYM (50%) + Poultry manure (50%) equivalent to 100 % RDN

T₅ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₆ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₇ : **T₃** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₈ : **T₄** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₉ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₀ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₁ : Sole foxtail millet without tree component

biomass was recorded with application of FYM + poultry manure + panchagavya spray (34.98 t ha^{-1}) when compared with sole foxtail millet with recommended organic nutrient sources without tree association (4.94 t ha^{-1}), no organic manurial treatment (27.52 t ha^{-1}), FYM (30.39 t ha^{-1}) and FYM + vermicompost (31.38 t ha^{-1}). Next best treatment was FYM + poultry manure + panchagavya alternated with vermiwash (34.88 t ha^{-1}). Other treatments were intermediary in their effect.

4.4.5.8.3 Below ground biomass production (t ha^{-1}) (cf. Table 38)

Observation on below ground biomass production was recorded at the end of the experiment during 2019, which ranged from 1.28 to 9.09 t ha^{-1} . Significantly higher biomass was recorded with FYM + poultry manure + panchagavya spray (9.09 t ha^{-1}) over all the treatments except FYM + poultry manure + panchagavya alternated with vermiwash spray (9.07 t ha^{-1}), FYM + vermicompost + vermiwash spray (8.90 t ha^{-1}), FYM + poultry manure (8.58 t ha^{-1}) and FYM + vermicompost + panchagavya spray (8.31 t ha^{-1}). Sole foxtail millet without tree component with recommended organic nutrient package recorded significantly lower biomass (1.28 t ha^{-1}) over all the treatments.

4.4.5.8.4 Total biomass production (t ha^{-1}) (cf. Table 38 and Fig. 19)

Total biomass production was calculated by adding biomass production in below and above grounds, which ranged from 6.23 to 44.07 t ha^{-1} . Application of FYM + poultry manure + panchagavya spray showed its significant superiority in total biomass production (44.07 t ha^{-1}) over FYM (38.29 t ha^{-1}), FYM + vermicompost (39.53 t ha^{-1}) and FYM + poultry manure + vermiwash spray (38.25 t ha^{-1}) and sole foxtail millet with recommended nutrient management practices without tree association (6.23 t ha^{-1}) and no organic manurial treatment (34.68 t ha^{-1}). Next best treatment was FYM + poultry manure + panchagavya alternated with vermiwash spray (43.95 t ha^{-1}).

4.4.5.9 Carbon stock and sequestration

4.4.5.9.1 Carbon stock (t ha^{-1})

4.4.5.9.1.1 Carbon stock in above ground (t ha^{-1}) (cf. Table 38 and Fig. 19)

Observation on carbon stock in above ground biomass was calculated at the end of the second year of the experimentation, which ranged from 2.47 to 17.49 t ha^{-1} .

In agroforestry system, significantly higher carbon stock in above ground biomass was observed with the application of FYM + poultry manure + panchagavya spray (17.49 t ha⁻¹) when compared with no organic manurial treatment (13.76 t ha⁻¹), FYM (15.19 t ha⁻¹), FYM + vermicompost (15.69 t ha⁻¹) and FYM + poultry manure + vermiwash spray (15.18 t ha⁻¹). Next best treatment was FYM + poultry manure + panchagavya alternated with vermiwash (17.44tha⁻¹). Other treatments showed their intermediary effect on carbon stock in above ground. While significantly lower carbon stock in above ground was with sole foxtail millet without tree association with recommended organic nutrient sources (2.47 t ha⁻¹).

4.4.5.9.1.2 Carbon stock in below ground (t ha⁻¹) (cf. Table 38 and Fig. 19)

Observation on carbon stock in below ground biomass was calculated at the end of the experiment during 2019, which ranged from 0.64 to 4.55 t ha⁻¹. In association with *Melia dubia* tree component, application of FYM + poultry manure + panchagavya spray resulted in significantly higher carbon stock in below ground (4.55 tha⁻¹) over all the treatments except FYM + poultry manure + panchagavya alternated with vermiwash spray (4.53 t ha⁻¹), FYM + poultry manure + vermiwash spray (4.45 t ha⁻¹), FYM + vermicompost + panchagavya alternated with vermiwash spray (4.25 t ha⁻¹), FYM + poultry manure + panchagavya spray (4.29 t ha⁻¹) and FYM + vermicompost + panchagavya spray (4.16 t ha⁻¹). Sole foxtail millet with recommended organic nutrient management practices without tree association recorded significantly lower carbon stock in below ground (0.64 t ha⁻¹) over all the treatments in agroforestry system.

4.4.5.9.1.2.3 Total carbon stock in biomass (t ha⁻¹) (cf. Table 38 and Fig. 19)

Total carbon stock was calculated by adding carbon stock in below and above ground biomass, which ranged from 3.11 to 22.03 t ha⁻¹. In agroforestry system, significantly higher carbon stock was observed with the application of FYM + poultry manure + panchagavya (22.03 t ha⁻¹) when compared with no organic manurial treatment (17.34 t ha⁻¹), FYM (19.14 t ha⁻¹) and FYM + vermicompost (19.77 t ha⁻¹). Significantly lower total carbon stock was registered with sole foxtail millet with recommended organic nutrient practices without tree component (3.11 t ha⁻¹). While, rest of the treatments were on par with each other.

4.4.5.9.2 Carbon sequestration (t ha⁻¹)

4.4.5.9.2.1 Carbon sequestration in above ground (t ha⁻¹) (cf. Table 38 and Fig. 19)

Observation on carbon sequestration in above ground biomass was calculated based on carbon stock in above ground biomass production at the end of the experiment, which ranged from 9.07 to 64.18 t ha⁻¹. Significantly higher carbon sequestration in above ground biomass was noticed with tree association under organic nutrient management practices over without tree association (9.07 t ha⁻¹). In agroforestry system, application of FYM + poultry manure + panchagavya spray showed its significant superiority in carbon sequestration (4.55 t ha⁻¹) over no organic manurial treatment (50.50 t ha⁻¹), FYM (55.76 t ha⁻¹), FYM + vermicompost (57.57 t ha⁻¹) and FYM + poultry manure + vermiwash spray (57.71 t ha⁻¹). Next best treatment was application of FYM + poultry manure + panchagavya alternated with vermiwash (64.00 t ha⁻¹) which showed significant superiority over rest of other treatments.

4.4.5.9.2.2 Carbon sequestration in below ground (t ha⁻¹) (cf. Table 38 and Fig. 19)

Observation on carbon sequestration in below ground biomass was calculated based on carbon stock in below ground biomass production at the end of the experiment, which ranged from 2.36 to 16.69 t ha⁻¹. Significantly higher carbon sequestration in below ground biomass was observed with the application of FYM + poultry manure + panchagavya spray (16.69 t ha⁻¹) over sole foxtail millet with recommended organic nutrient management package without tree component (2.36 t ha⁻¹), no organic manures treated plot (13.13 t ha⁻¹), FYM (14.50 t ha⁻¹) and FYM + vermicompost (14.97 t ha⁻¹).

4.4.5.9.2.3 Total carbon sequestration (t ha⁻¹) (cf. Table 38 and Fig. 19)

Total carbon sequestration in biomass was the sum total of carbon sequestration in above and below ground in both agroforestry and non agroforestry system which ranged from 11.42 to 80.87 t ha⁻¹. Significantly higher carbon sequestration was observed with tree association than the without tree. Among the organic manurial treatments with *Melia dubia*, significantly higher carbon sequestration was observed with FYM + poultry manure + panchagavya (80.87 t ha⁻¹) when compared with no organic treatments (63.64 t ha⁻¹), FYM (70.26 t ha⁻¹) and FYM + vermicompost (72.54 t ha⁻¹). Next best treatment was FYM + poultry manure + panchagavya alternated with vermiwash (80.64 t ha⁻¹),

Table 38. *Melia dubia* wood volume, biomass, C stock and C sequestration under organic nutrient management practices in foxtail millet as an inter crop in *Melia dubia* based agroforestry system (At the end of second year-2019)

Treatments	Wood volume (t ha ⁻¹)	Biomass above ground (t ha ⁻¹)	Biomass below ground (t ha ⁻¹)	Total biomass (t ha ⁻¹)	C stock above ground (t ha ⁻¹)	C stock below ground (t ha ⁻¹)	Total C stock (t ha ⁻¹)	C sequestration above ground (t ha ⁻¹)	C sequestration below ground (t ha ⁻¹)	Total C sequestration (t ha ⁻¹)
T₁	49.99	27.52	7.16	34.68	13.76	3.58	17.34	50.50	13.13	63.64
T₂	54.13	30.39	7.90	38.29	15.19	3.95	19.14	55.76	14.50	70.26
T₃	55.45	31.38	8.16	39.53	15.69	4.08	19.77	57.57	14.97	72.54
T₄	58.46	33.01	8.58	41.59	16.50	4.29	20.79	60.57	15.75	76.31
T₅	55.67	31.97	8.31	40.28	15.98	4.16	20.14	58.66	15.25	73.91
T₆	61.48	34.98	9.09	44.07	17.49	4.55	22.03	64.18	16.69	80.87
T₇	60.44	34.25	8.90	43.15	17.12	4.45	21.58	62.85	16.34	79.19
T₈	54.55	32.36	7.89	38.25	15.18	3.95	20.13	57.71	15.49	74.20
T₉	57.04	32.68	8.50	41.17	16.34	4.25	20.59	59.96	15.59	75.55
T₁₀	61.04	34.88	9.07	43.95	17.44	4.53	21.97	64.00	16.64	80.64
T₁₁	-	4.94	1.28	6.23	2.47	0.64	3.11	9.07	2.36	11.42
S.Em ±	-	1.09	0.28	1.37	0.54	0.14	0.69	2.00	0.52	2.52
C. D. at 5%	-	3.21	0.83	4.05	1.61	0.42	2.02	5.89	1.53	7.42

T₁ : No organic manure (Control)

T₂ : FYM equivalent to 100 % RDN

T₃ : FYM (50%) + Vermicompost (50%) equivalent to 100 % RDN

T₄ : FYM (50%) + Poultry manure (50%) equivalent to 100 % RDN

T₅ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₆ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₇ : **T₃** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₈ : **T₄** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₉ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₀ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₁ : Sole foxtail millet without tree component

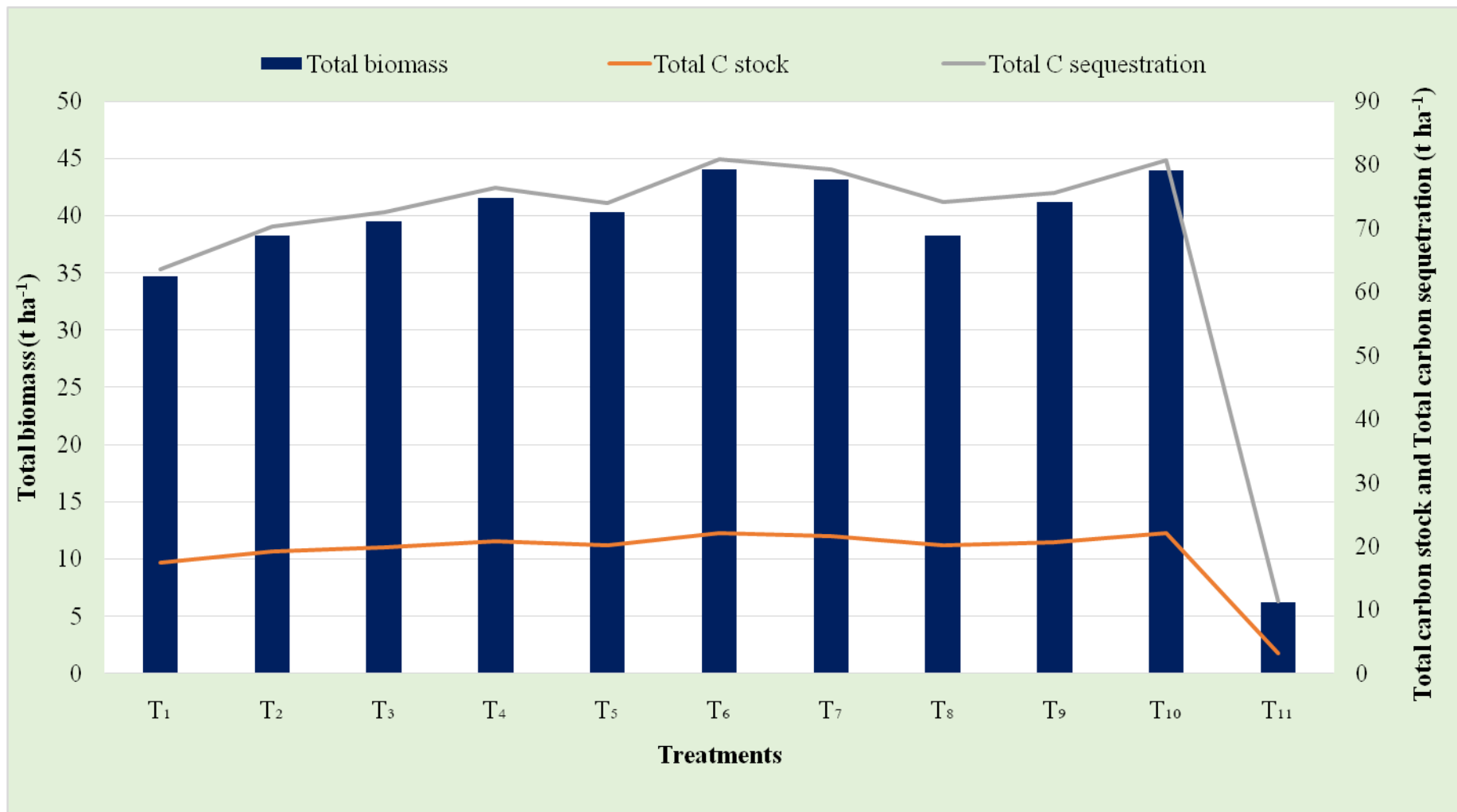


Fig. 19. *Melia dubia* tree total biomass, total C stock and total C sequestration under organic nutrient management practices foxtail millet- *Melia dubia* agroforestry system

which in turn showed its significant superiority over rest of other treatments. Other treatments were intermediary in their effect. The significantly lower total carbon sequestration was observed with sole foxtail millet with recommended organic nutrient practices without tree component (11.42 t ha⁻¹).

Agroforestry mitigates climate change through carbon sequestration. Growing of trees only for carbon is not a feasible choice for farmers in irrigated agro-ecosystem, but the carbon market is gearing up in the present era as a result of additional revenue in terms of carbon trading. The present study highlights that *Melia dubia* + foxtail millet agroforestry system is a better option than the sole agricultural cropping in respect of climate mitigation and sustainable productivity and doubling farmer's income. Hence, it is required to proceed with the system; otherwise the profit gained in-terms of carbon sequestration in the system would revert to the original state. Higher carbon sequestration with various agroforestry system was also reported by Kumar (2010) in *Populus deltoids* + wheat, Chauhan *et al.* (2015) in wheat + poplar based agroforestry systems and Chandana *et al.* (2020) in pearl millet + *Melia dubia* agroforestry systems.

4.4.6 Economic analysis

The acceptance of any technology by the farmer ultimately depends on economics involved in the production system. Among the different indicators of monetary efficiency, the economics in terms of net returns and benefit cost ratio have a greater impact on acceptance of technology.

4.4.6.1 Crop economic analysis

4.4.6.1.1 Gross returns (Rs. ha⁻¹) (cf. Table 39)

In pooled data, significantly higher gross returns were realized in sole foxtail millet with recommended organic nutrient practice without tree component (Rs. 56,704 ha⁻¹) when compared with foxtail millet cultivated in agroforestry system under different organic nutrient management practices (Rs 27,730 to 50,443 ha⁻¹). In agroforestry system, application of FYM + poultry manure + panchagavya alternated with vermiwash spray recorded significantly higher gross returns (Rs. 50443 ha⁻¹) over no organic manurial treatment (Rs. 27,730 ha⁻¹), FYM (Rs. 37,789 ha⁻¹), FYM + vermicompost (Rs. 41,736 ha⁻¹) and FYM + poultry manure application (Rs. 43,832 ha⁻¹). While, no organic

manurial treatment resulted in significantly lower gross returns over all other treatments. Similar trend was followed during 2018 and 2019.

4.4.6.1.2 Net returns (Rs. ha⁻¹) (cf. Table 39)

In pooled data, significantly higher net returns were realized in sole foxtail millet with nutrient management through organics without tree association (Rs.34,002 ha⁻¹) over tree association with *Melia dubia* under different organic nutrient management practices (Rs 13,978 to 28,631 ha⁻¹). In agroforestry system, application of FYM + poultry manure + panchagavya alternated with vermiwash spray recorded significantly higher net returns (Rs. 28,631 ha⁻¹) when compared with all the treatments except FYM + poultry manure + vermiwash spray (Rs. 26402 ha⁻¹) and FYM + vermicompost + panchagavya alternated with vermiwash spray (Rs. 26205 ha⁻¹). No organic manurial treatment recorded significantly lower net returns (Rs. 13,978 ha⁻¹) compared to all treatments except FYM (Rs. 16,337 ha⁻¹). Application of FYM or in combination with vermicompost or poultry manure showed significant inferiority over their corresponding treatments with liquid organic manures.

4.4.6.1.3 Benefit cost ratio (cf. Table 39)

Benefit cost ratio followed similar trend as that of gross and net returns. Significantly higher benefit cost ratio was realized with sole foxtail millet grown organically with recommended nutrient schedule without tree component (2.50) when compared with foxtail millet as an inter crop in *Melia dubia* based agroforestry system under different organic nutrient management practices (1.76 to 2.31). In agroforestry system, FYM + poultry manure + panchagavya alternated with vermiwash spray recorded significantly higher benefit cost ratio (2.31) over all the treatments except FYM + poultry manure + vermiwash spray (2.24). Application of FYM alone (1.76) resulted in significantly lower benefit cost ratio when compared to all treatments.

Reduced gross and net returns from foxtail millet cultivation in agroforestry system compared to sole crop without tree combination was mainly attributed to significant reduction in yield due to shade effect. This can be recuperated from the income obtained through *Melia dubia* trees. The results were in accordance with the findings of Anand *et al.* (2012) and Patel *et al.* (2018).

4.4.6.2 System economic analysis

4.4.6.2.1 Gross returns (Rs. ha⁻¹) (cf. Table 39 and Fig. 20)

At the end of sixth year plantation (2019), in pooled data, significant variation in gross returns was noticed between cultivation of foxtail millet with and without tree components. Significantly lower gross returns were observed in sole foxtail millet with recommended organic nutrient practice without tree component (Rs 59,813 ha⁻¹). Among the treatments in agroforestry system, significantly higher gross returns were realized with application of FYM + poultry manure + panchagavya (Rs. 4,05,577 ha⁻¹) followed by FYM + poultry manure + panchagavya alternated with vermiwash spray (Rs. 4,05,368 ha⁻¹), which were significantly superior over all other treatments. No organic manurial treatment recorded significantly lower gross returns (Rs. 3,17,189 ha⁻¹) in agroforestry system over all other treatments.

4.4.6.2.2 Net returns (Rs. ha⁻¹) (cf. Table 39 and Fig. 20)

At the end of sixth year of plantation (2019), in pooled data, net returns were significantly influenced by cultivation of foxtail millet with and without tree component.

Significantly higher system net returns were obtained in all organic manurial treatments with agroforestry system (From Rs. 2,40,937 to 3,21,056 ha⁻¹ with an average of Rs. 289,920 ha⁻¹) over the treatment foxtail millet cultivation with recommended organic nutrient schedule in non agroforestry system (Rs. 37,111 ha⁻¹). In agroforestry system, significantly higher net returns of the system of Rs. 3,21,056 ha⁻¹ were obtained with FYM+ poultry manure + panchagavya alternated with vermiwash spray except FYM + poultry manure + foliar spray of 3% panchagavya (Rs. 3,20,715 ha⁻¹) over all other treatments. The next best organic manurial treatment was FYM + vermicompost + vermiwash (Rs. 3,15,179 ha⁻¹). Treatments which received FYM + vermicompost and FYM + poultry manure showed significantly lower net returns from the system (Rs. 2,80,369 and Rs. 3,01,153 ha⁻¹, respectively) when compared to their corresponding treatment with foliar spray of panchagavya (Rs. 2,85,937 and Rs. 3,15,179 ha⁻¹, respectively), vermiwash (Rs. 3,20,715 and Rs. 2,70,214 ha⁻¹, respectively). No organic manurial treatment recorded significantly lower net returns from the system (Rs. 2,40,937 ha⁻¹).

4.4.6.2.3 Benefit cost ratio (cf. Table 39 and Fig. 20)

In pooled data, significantly higher benefit cost ratio from the whole system was realized with application of FYM + poultry manure + panchagavya alternated with vermiwash spray (4.81) followed by application of FYM + poultry manure + panchagavya (4.78) and FYM + vermicompost + vermiwash spray (4.73), which were significantly superior over all other treatments. No organic manurial treatment recorded significantly lower benefit cost ratio in agroforestry system (4.16) compared to all the treatments except FYM alone (4.19) and FYM + vermicompost + vermiwash spray (4.23). Foxtail millet cultivated organically with nutrient management schedule without tree component recorded significantly lower benefit cost ratio (2.63) over all other treatments.

It is evident that intercropping of foxtail millet with *Melia dubia* showed maximum gross and net monetary returns when compared to sole cropping without tree component. Improved monetary returns from the system (tree + crop) are mainly due to higher biomass production from the tree in the form of timber with better performance of foxtail millet under organic nutrient management practices. This clearly shows that arable crops like foxtail millet when grown as an intercrop with the trees exhibit compatibility with the trees in mutual sharing of the natural resources available. Agroforestry practices fetched higher returns when compared to sole crop. These results are in accordance with results obtained by Jain and Singh (1999) in wheat with poplar tree, Devaranavadgi *et al.* (2005) in chickpea with *Hardwickia binata*, Mutanal *et al.* (2009) in groundnut and sorghum with teak, Aarif *et al.* (2010) in sunflower with *Hardwickia* system, Nandal and Kumar (2010) in wheat, barley and berseem with *Melia azedarach*, Wekesa *et al.* (2012) in greengram with *Melia* species, Vishwanath (2013) in soybean with *Madhuca latifolia*, Rahangdale *et al.* (2014) in green gram with bamboo species and Chandana *et al.* (2020) in pearl millet with *Melia dubia* based agroforestry systems. Among the organic manurial treatments with tree association, higher net returns from the system were noticed with FYM + poultry manure + panchagavya alternated with vermiwash, FYM+vermicompost + panchagavya alternated with vermiwash, FYM + poultry manure + panchagavya, FYM + poultry manure + vermiwash and FYM + vermicompost + panchagavya than FYM + vermicompost, FYM + poultry manure, FYM alone and no organic manurial practice, thus reflecting that the reduction in yield of foxtail millet can be minimized for obtaining

Table 39. Economic analysis of foxtail millet cultivation and system analysis of *Melia dubia* based agroforestry under organic nutrient management practices

Treatments	Crop										Agroforestry system (Crop + <i>Melia dubia</i>) at the end of 6 th year of plantation (2019)			
	Gross returns (Rs. ha ⁻¹)			Cost of cultivation (Rs. ha ⁻¹)	Net returns (Rs. ha ⁻¹)			B : C ratio			Gross returns (Rs. ha ⁻¹)	Cost of cultivation (Rs. ha ⁻¹)	Net returns (Rs. ha ⁻¹)	B : C ratio
	2018	2019	Pooled		2018	2019	Pooled	2018	2019	Pooled				
T₁	26316	29145	27730	13752	12564	15393	13978	1.91	2.12	2.02	317189	76252	240937	4.16
T₂	35462	40116	37789	21452	14010	18664	16337	1.65	1.87	1.76	352032	83952	268080	4.19
T₃	38759	44712	41736	21357	17402	23355	20379	1.81	2.09	1.95	364226	83857	280369	4.34
T₄	40303	47360	43832	20562	19741	26798	23270	1.96	2.30	2.13	384215	83062	301153	4.63
T₅	44518	50843	47680	23157	21361	27686	24523	1.92	2.20	2.06	371593	85657	285937	4.34
T₆	44789	51317	48053	22362	22427	28955	25691	2.00	2.29	2.15	405577	84862	320715	4.78
T₇	42664	51498	47081	22057	20607	29441	25024	1.93	2.33	2.13	399735	84557	315179	4.73
T₈	44122	51206	47664	21262	22860	29944	26402	2.08	2.41	2.24	353976	83762	270214	4.23
T₉	45642	51981	48812	22607	23035	29374	26205	2.02	2.30	2.16	380662	85107	295555	4.47
T₁₀	47219	53667	50443	21812	25407	31855	28631	2.16	2.46	2.31	405368	84312	321056	4.81
T₁₁	53596	59813	56704	22702	30894	37111	34002	2.36	2.63	2.50	59813	22702	37111	2.63
S.Em ±	1235	1299	949	-	1235	1299	949	0.05	0.06	0.05	1299	-	1299	0.03
C. D. at 5%	3645	3833	2800	-	3645	3833	2800	0.17	0.18	0.14	3833	-	3833	0.09

T₁ : No organic manure (Control)

T₂ : FYM equivalent to 100 % RDN

T₃ : FYM (50%) + Vermicompost (50%) equivalent to 100 % RDN

T₄ : FYM (50%) + Poultry manure (50%) equivalent to 100 % RDN

T₅ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₆ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 and 45 DAS

T₇ : **T₃** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₈ : **T₄** + Foliar spray of Vermiwash @ 5 % at 30 and 45 DAS

T₉ : **T₃** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₀ : **T₄** + Foliar spray of Panchagavya @ 3 % at 30 DAS and Vermiwash @ 5 % at 45 DAS

T₁₁ : Sole foxtail millet without tree component

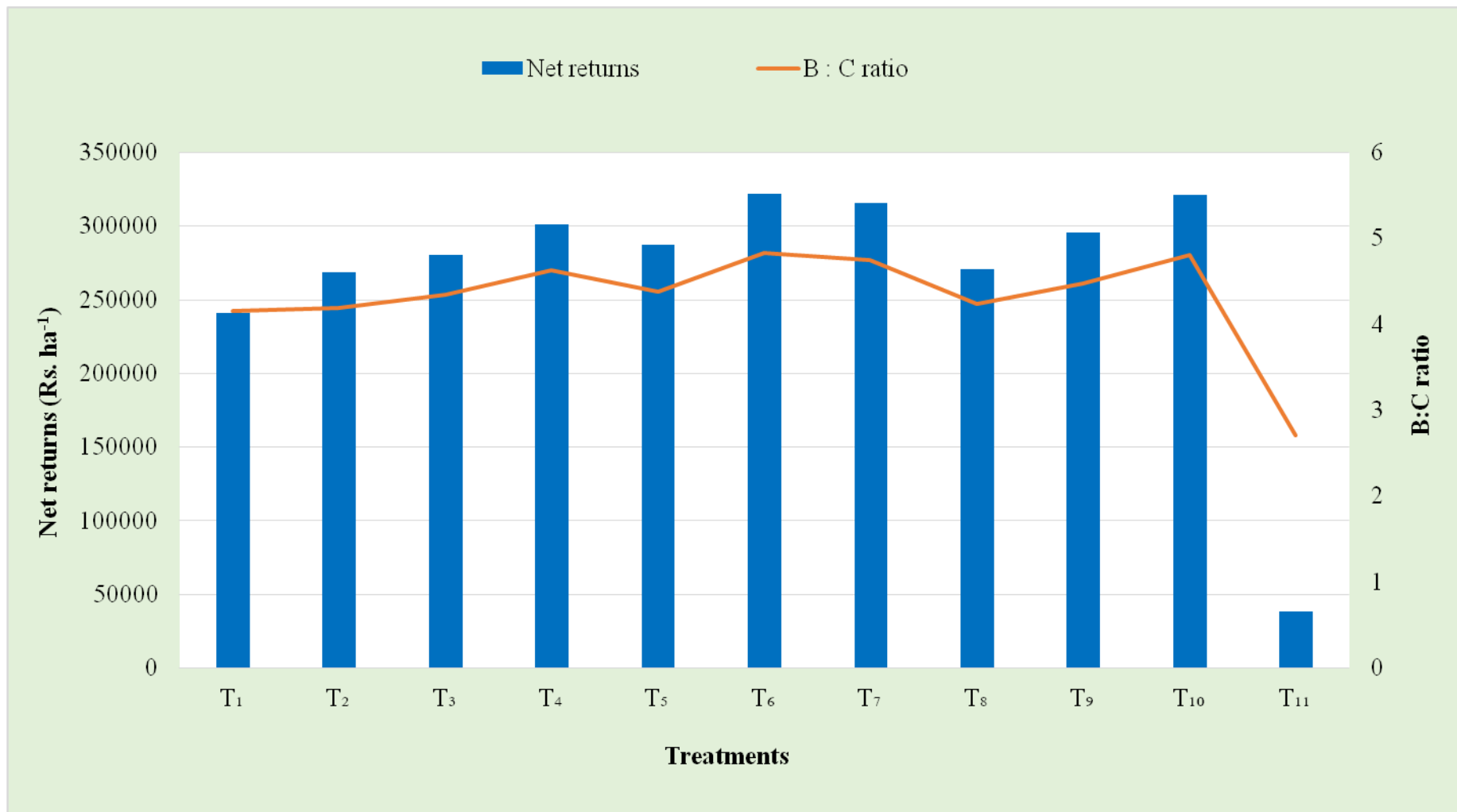


Fig. 20. System economic analysis of foxtail millet – *Melia dubia* based agroforestry as influenced by organic nutrient management practices



Plate 2a: General view of experiment –III



Plate 2b: Foxtail millet without tree component

Plate 2. Performance of foxtail millet under promising organic nutrient management practices in *Melia dubia* based agroforestry system



Plate 2. Performance of foxtail millet under promising organic nutrient management practices in *Melia dubia* based agroforestry system

higher net returns with *Melia dubia* based system when organic manures (FYM, vermicompost and poultry manure) and liquid fermented organics (Panchagavya and vermiwash) were combined and utilized in intergrated manner.

4.5 Experiment - IV: Performance of *Melia dubia* under high density planting system

Melia dubia is an indigenous fast growing tree species with multipurpose uses like pulpwood, timber, fuel wood and plywood and fits as a suitable species for plantation under various agroclimatic conditions. In the recent scenario, the species has greater attraction by farmers, foresters and plantation growers. The growing demand for timber can be met to some extent by utilizing alternate species and increasing the timber production through intensive silviculture management. The choice of planting density is a primary agroforestry decision which considers the tradeoff between individual tree size and stand production, thus affecting quality and quantity of products throughout the rotation. Hence, the plantations of fast growing and short rotation woody crops like *Melia dubia* have gained more importance in respect of carbon sequestration apart from providing income from wood products. In spite of its multi benefits, there are hardly few studies on evaluating the early growth and productivity of the species under different plant densities. Keeping these points in view, the present study was undertaken to estimate growth, volume and optimum productivity of the species in relation to different planting densities (from 370 to 5000 trees ha⁻¹) at different time intervals during early stage of plantation.

4.5.1 Tree height (m) (cf. Table 40 and Fig. 21)

Observation on tree height of *Melia dubia* was recorded for two years from 2018 to 2019 season at three months' interval. There was no significant difference in tree height upto one year, which ranged from 0.85 to 0.97 m, 1.29 to 1.33 m, 1.60 to 1.92 m and 1.96 to 2.58 m at 3, 6, 9 and 12 months after planting (MAP), respectively. Maximum tree height was recorded under closer spacing (2 m x 1 m with 5000 trees ha⁻¹) as well as wider spacing (9 m x 3 m with 370 trees ha⁻¹) at all the growth stages. At 15 MAP, significantly higher tree height was recorded at wider spacing of 9 m x 3 m with 370 trees ha⁻¹ (3.67 m) when compared with tree height at different plant densities but on par with plant density of 5000 trees ha⁻¹ (3.17 m) and 3333 trees ha⁻¹ (3.11 m). Similar trend was observed at 18, 21 and 24 MAP. At the end of the experiment (24 MAP), significantly higher tree height was recorded under plant density of 370 trees ha⁻¹ (7.32 m) followed by 5000 trees ha⁻¹ (6.98 m) when compared to all other treatments. Rest of the treatments were intermediary in their effect. On an average 120.32 per cent increment in tree height

Table 40. Tree height of *Melia dubia* at different growth stages under high density planting system

Treatments	Tree height (m)							
	3 MAP	6 MAP	9 MAP	12 MAP	15 MAP	18 MAP	21 MAP	24 MAP
T₁ : 2 m x 1 m (5000 trees ha ⁻¹)	0.92	1.32	1.92	2.56	3.17	4.18	5.25	6.98
T₂ : 2 m x 2 m (2500 trees ha ⁻¹)	0.95	1.36	1.87	2.45	2.95	3.86	4.68	6.41
T₃ : 3 m x 1 m (3333 trees ha ⁻¹)	0.88	1.33	1.88	2.52	3.11	4.09	4.86	6.47
T₄ : 3 m x 2 m (1667 trees ha ⁻¹)	0.97	1.23	1.73	2.21	2.80	3.64	4.68	6.14
T₅ : 4 m x 1 m (2500 trees ha ⁻¹)	0.89	1.19	1.68	2.28	2.72	3.51	4.64	6.26
T₆ : 4 m x 2 m (1200 trees ha ⁻¹)	0.86	1.16	1.60	1.96	2.06	3.34	3.57	5.25
T₇ : 9 m x 3 m (370 trees ha ⁻¹)	0.85	1.29	1.81	2.58	3.67	4.49	5.52	7.32
S.Em.±	0.04	0.06	0.12	0.22	0.20	0.17	0.28	0.28
C.D. at 5%	NS	NS	NS	NS	0.62	0.52	0.86	0.88

MAP: Months after planting

NS: Not significant

was observed from 15 MAP to 24 MAP, thus indicating fast growth habit of *Melia dubia*. Wider spacing between tree rows resulted in taller plants and greater diameter growth, resulting in higher per plant productivity. Similar results were also reported with wider spacing by Prasad *et al.* (2015) in *Leucaena leucocephala* and Zahabu *et al.* (2015) in teak while, Singh *et al.* (2016) noticed taller guava plants at higher plant densities.

4.5.2 Bole height (m) (cf. Table 41 and Fig. 21)

Observation on bole height was recorded from 15 months after planting (MAP). At 15 MAP, significantly higher bole height was recorded at lower plant density *i.e.*, 370 trees ha⁻¹ (2.87 m) when compared to bole height in different plant densities except at plant density of 5000 trees ha⁻¹ (2.47 m) and 3333 trees ha⁻¹ (2.43 m). Similar trend was followed at 18, 21 and 24 MAP. At end of the experiment, significantly higher bole height was recorded under plant population of 370 trees ha⁻¹ (5.39) over all other treatments. This was followed by the treatment of 5000 trees ha⁻¹ (4.99 m). Other treatments were intermediary in their effect. Similar effect was reported by Singh *et al.* (2016) in guava who observed that tree height and trunk circumference were highest at the planting distance of 3.0 x 1.5 m.

4.5.3 Girth at breast height (cm) (cf. Table 41 and Fig. 21)

Girth at breast height (GBH) was significantly influenced by different levels of plant densities with varied spacings. At 15 MAP, significantly higher GBH (17.00 cm) was recorded at wider row spacing of 9 m x 3 m with 370 trees ha⁻¹ over all other levels of spacings. At closer spacing of 2 m x 1 m, significantly lower GBH (8.68 cm) was recorded when compared to all other treatments. Next best treatment was with 4 m x 2 m spacing which was at par with 3 m x 2 m spacing. At 24 MAP, the treatments which were in decreasing order with respect to effect on GBH were 9 m x 3 m (30.86 cm), 4 m x 2 m (24.77 cm), 3 m x 2 m (20.47 cm), 4 m x 1 m (20.44 cm), 3 m x 1 m (19.82 cm), 2 m x 2 m (19.08 cm) and 2 m x 1 m (14.68 cm).

Table 41. Bole height, girth at breast height and diameter at breast height of *Melia dubia* tree at different growth stages under high density planting system

Treatments	Bole height (m)				Girth at breast height -GBH (cm)				Diameter at breast height -DBH (cm)			
	15 MAP	18 MAP	21 MAP	24 MAP	15 MAP	18 MAP	21 MAP	24 MAP	15 MAP	18 MAP	21 MAP	24 MAP
T₁ : 2 m x 1 m (5000 trees ha ⁻¹)	2.47	3.40	3.89	4.99	8.68	11.41	12.68	14.68	8.43	10.88	12.06	13.87
T₂ : 2 m x 2 m (2500 trees ha ⁻¹)	2.30	3.14	3.47	4.58	10.51	13.71	16.43	19.08	10.20	13.18	15.80	18.17
T₃ : 3 m x 1 m (3333 trees ha ⁻¹)	2.43	3.32	3.60	4.62	9.99	13.17	17.07	19.82	9.70	12.53	16.41	18.87
T₄ : 3 m x 2 m (1667 trees ha ⁻¹)	2.18	2.96	3.47	4.39	12.87	16.78	17.78	20.47	12.49	16.14	16.95	19.49
T₅ : 4 m x 1 m (2500 trees ha ⁻¹)	2.12	2.85	3.44	4.47	10.76	14.09	17.31	20.44	10.45	13.50	16.58	19.07
T₆ : 4 m x 2 m (1200 trees ha ⁻¹)	1.61	2.72	2.64	4.24	14.20	18.52	21.33	24.77	13.79	17.81	20.51	23.59
T₇ : 9 m x 3 m (370 trees ha ⁻¹)	2.87	3.65	4.09	5.39	17.00	22.20	26.68	30.86	16.51	21.32	25.34	29.14
S.Em.±	0.16	0.14	0.21	0.17	0.49	0.67	0.83	0.87	0.48	0.61	0.76	0.87
C.D. at 5%	0.48	0.42	0.64	0.53	1.51	2.05	2.55	2.67	1.47	1.89	2.33	2.68

MAP: Months after planting

GBH: Girth at breast height

DBH: Diameter at breast height

4.5.4 Diameter at breast height (cm) (cf. Table 41 and Fig. 21)

Diameter at breast height (DBH) was significantly influenced by different levels of spacing. At 15 MAP, significantly higher DBH (16.51 cm) was recorded at wider row spacing (9 m x 3 m) when compared to all other levels of spacing. At closer spacing of 2 m x 1 m, significantly lower DBH (8.43 cm) was recorded over all other treatments (8.43 cm). Next best treatment was with 4 m x 2 m spacing which was on par with 3 m x 2 m spacing. At 24 MAP, the treatments in decreasing order with respect to effect on DBH were 9 m x 3 m (29.14 cm), 4 m x 2 m (23.59 cm), 3 m x 2 m (19.49 cm), 4 m x 1 m (19.07 cm), 3 m x 1 m (18.87 cm), 2 m x 2 m (18.17 cm) and 2 m x 1 m (13.87 cm).

The increased tree growth with low density plantations might be due to the more availability of light, water and nutrients resulting in increase in crown size, leaf area and synthesis of carbohydrates and hormonal growth regulators. These changes might have increased downward transport of carbohydrates and hormonal growth regulators in the stem resulting eventual increase in cambial growth and redistribution of wood production along the tree stem. Khan and Chaudhary (2007) revealed that, poplar trees put significantly greater diameter (DBH) growth under the spacing of 3.7 x 12.1 m. Zahabu *et al.* (2015) who reported that diameter at breast height and total height of teak increased with increasing the spacing. Mean annual increment increased significantly with increasing spacing while spacing did not have significant effect on total volume production and basal area. Rocha *et al.* (2016) opined that wider spacing had more advantages than closer spacing.

4.5.5 Collar diameter (cm) (cf. Table 42 and Fig. 21)

Observation on collar diameter of *Melia dubia* tree was recorded for two years at three months' interval. There was no significant difference in collar diameter upto 9 months after planting (MAP), which ranged from 3.52 to 4.25 cm, 5.82 to 8.16 cm and 8.83 to 14.38 cm at 3, 6 and 9 MAP, respectively. At 12 MAP, significantly higher collar diameter was recorded at wider spacing of 9 m x 3 m with 370 trees ha⁻¹ (22.25 cm) when compared to all other treatments. Next best treatment was 4 m x 2 m spacing with 1200 trees ha⁻¹. Similar trend was followed at 15, 18, 21 and 24 MAP. At the end of the experiment, significantly higher collar diameter of the tree was recorded under wider spacing of 9 m x 3 m (38.09 cm). This may be due to the fact that there was no

Table 42. Collar diameter of *Melia dubia* tree at different growth stages under high density planting system

Treatments	Collar diameter (cm)							
	3 MAP	6 MAP	9 MAP	12 MAP	15 MAP	18 MAP	21 MAP	24 MAP
T₁ : 2 m x 1 m (5000 trees ha ⁻¹)	3.52	5.99	8.83	11.36	13.06	14.69	17.34	20.60
T₂ : 2 m x 2 m (2500 trees ha ⁻¹)	3.71	6.12	10.15	13.75	15.81	17.79	20.99	24.49
T₃ : 3 m x 1 m (3333 trees ha ⁻¹)	3.53	5.82	8.93	13.08	15.04	16.92	19.97	20.69
T₄ : 3 m x 2 m (1667 trees ha ⁻¹)	4.12	7.63	11.74	16.84	19.36	21.78	25.70	29.83
T₅ : 4 m x 1 m (2500 trees ha ⁻¹)	3.80	6.26	9.71	14.08	16.20	18.22	21.50	25.70
T₆ : 4 m x 2 m (1200 trees ha ⁻¹)	4.01	8.10	13.15	18.58	21.37	24.04	28.37	32.77
T₇ : 9 m x 3 m (370 trees ha ⁻¹)	4.25	8.16	14.38	22.25	25.59	28.79	33.97	38.09
S.Em.±	0.32	0.81	1.86	0.64	0.74	0.83	0.98	1.12
C. D. at 5%	NS	NS	NS	1.98	2.27	2.56	3.02	3.45

MAP: Months after planting

NS: Not significant

competition between trees for space, water and nutrients. These results are also in conformity with findings of Forrester *et al.* (2013) who reported that mean *Eucalyptus globulus* tree diameter of the whole stand and the basal area of the largest diameter were higher at lower planting densities, whereas whole stand basal area was greater at higher planting densities.

4.5.6 Tree volume ($\text{m}^3 \text{ha}^{-1}$) (cf. Table 43 and Fig. 21)

Observation on volume of *Melia dubia* tree was calculated based on tree height and collar diameter at three months' interval. Significant difference in tree volume due to different levels of spacing *ie* plant populations was observed at different time intervals. At 3 MAP, significantly higher volume of tree ($4.51 \text{ m}^3 \text{ha}^{-1}$) was noticed with closer spacing (2 m x 1 m) when compared to all other treatments owing to higher plant population of 5000 trees ha^{-1} . Next best treatment was with spacing of 3 m x 1 m, which recorded significantly higher tree volume ($2.88 \text{ m}^3 \text{ha}^{-1}$) when compared to 4 m x 1 m ($2.57 \text{ m}^3 \text{ha}^{-1}$) and 3 m x 2 m ($2.14 \text{ m}^3 \text{ha}^{-1}$). Wider spacing of 9 m x 3 m recorded significantly lower volume of tree ($1.31 \text{ m}^3 \text{ha}^{-1}$) when compared to all other treatments owing to lesser plant population. Similar trend was followed in all duration. At 24 MAP, significantly higher volume of tree was noticed in closer spacing of 2 m x 1m with 5000 trees ha^{-1} ($1171.81 \text{ m}^3 \text{ha}^{-1}$) over all the treatments. Treatments which were in decreasing order with respect to effect on tree volume were 2 m x 1 m ($1171.81 \text{ m}^3 \text{ha}^{-1}$), 4 m x 1 m ($806.27 \text{ m}^3 \text{ha}^{-1}$), 2 m x 2 m ($755.69 \text{ m}^3 \text{ha}^{-1}$), 3 m x 2 m ($736.49 \text{ m}^3 \text{ha}^{-1}$), 3 m x 1 m ($723.20 \text{ m}^3 \text{ha}^{-1}$), 4 m x 2 m ($621.98 \text{ m}^3 \text{ha}^{-1}$) and 9 m x 3 m ($287.67 \text{ m}^3 \text{ha}^{-1}$). Bhardwaj *et al.* (2001) also reported maximum biomass of *Populus deltoides* in the closer spacings. Guangyou *et al.* (2016) observed that *E. urophylla* plantation density had a negative correlation with height, DBH and standing volume growth. Similar effect was reported by Singh *et al.* (2016) in guava, where in they observed higher yield per unit area with closer spacing.

4.5.7 Tree canopy spread (m) (cf. Table 44)

Observation on tree canopy spread was recorded from 15 months after planting at 3 months' interval in North - South (N-S) and East - West (E-W) directions. In general, higher canopy spread was recorded with E-W direction than N-S direction. At 15 MAP, canopy spreading in N-S direction was significantly higher with spacing of 9 m x 3 m (0.43 m) when compared with all the treatments except 4 m x 2 m, 3 m x 2 m and

Table 43. Volume of *Melia dubia* tree at different growth stages under high density planting system

Treatments	Tree volume (m ³ ha ⁻¹)							
	3 MAP	6 MAP	9 MAP	12 MAP	15 MAP	18 MAP	21 MAP	24 MAP
T₁ : 2 m x 1 m (5000 trees ha ⁻¹)	4.51	18.74	60.88	129.64	211.64	354.22	619.14	1171.81
T₂ : 2 m x 2 m (2500 trees ha ⁻¹)	2.56	10.22	38.14	90.93	145.69	239.19	405.84	755.69
T₃ : 3 m x 1 m (3333 trees ha ⁻¹)	2.88	11.88	39.71	115.28	181.73	306.46	500.02	723.20
T₄ : 3 m x 2 m (1667 trees ha ⁻¹)	2.14	9.56	33.21	82.37	137.92	227.08	406.82	736.49
T₅ : 4 m x 1 m (2500 trees ha ⁻¹)	2.57	9.79	31.05	88.57	140.75	232.88	433.43	806.27
T₆ : 4 m x 2 m (1200 trees ha ⁻¹)	1.31	7.30	27.50	63.63	88.56	182.32	269.97	621.98
T₇ : 9 m x 3 m (370 trees ha ⁻¹)	0.45	2.53	11.07	36.87	70.15	108.96	184.83	287.67
S.Em.±	0.27	2.08	5.50	11.81	14.77	23.70	36.26	80.91
C. D. at 5%	0.83	6.42	16.94	36.38	45.49	73.03	111.73	249.29

MAP: Months after planting

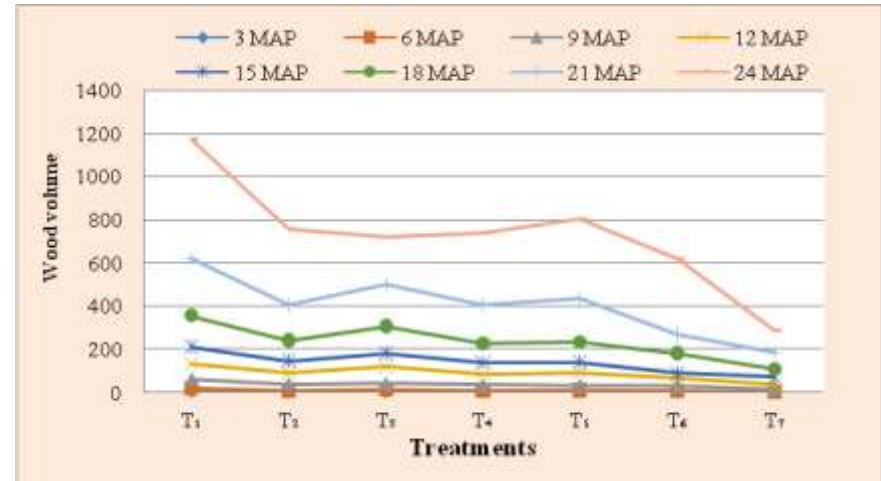
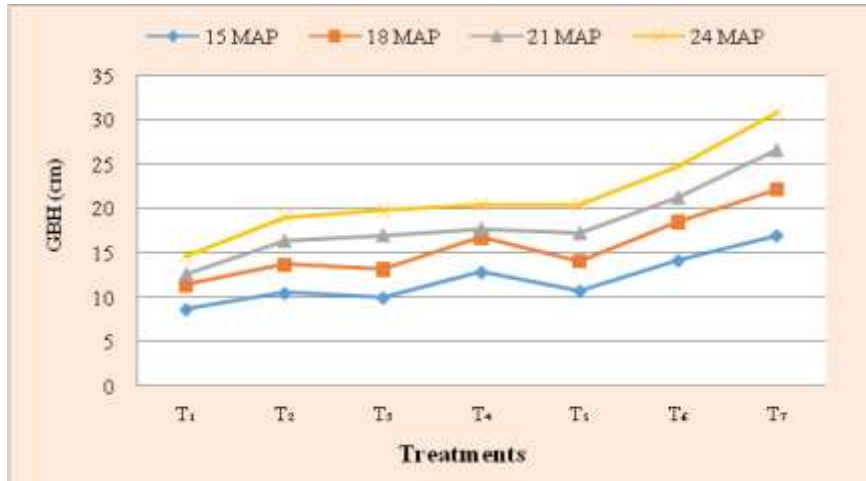
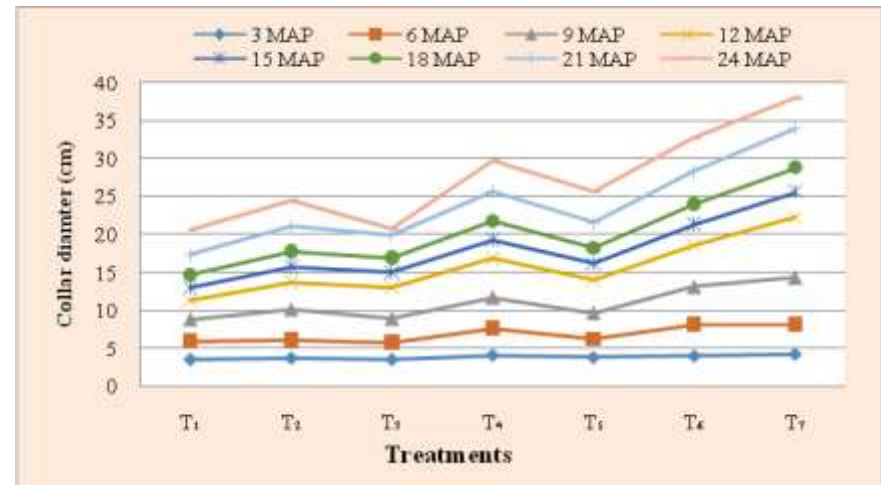
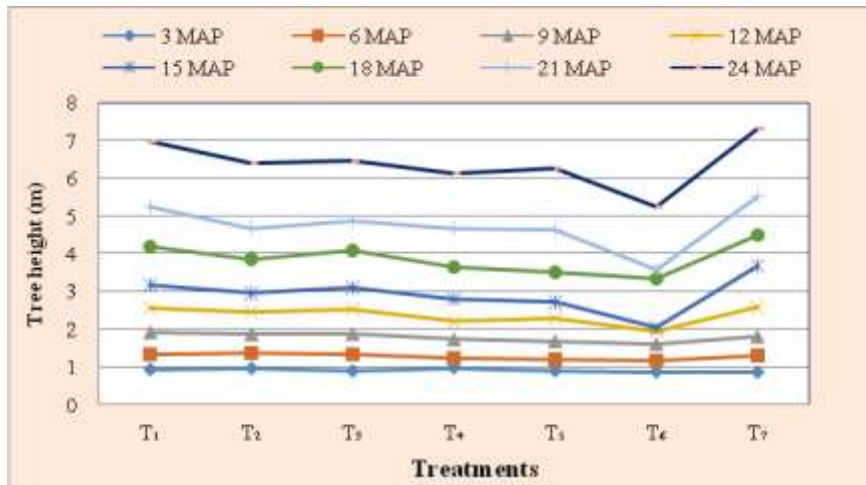


Fig. 21. Effect different levels of spacing on *Melia dubia* tree height, collar diameter, GBH and wood volume at three months' interval

2 m x 2 m spacing . In E-W direction, canopy spread was significantly higher with wider spacing *i.e.*, 9 m x 3 m (0.48 m). Similar trend was followed at different intervals. At 24 MAP in N-S direction, significantly higher canopy spread was observed in 9 m x 3 m spacing (1.36 m) when compared with all other treatments. The similar effect was seen in E-W direction. A marked variation was noticed among different treatments on canopy spread (NS/EW). Similar effect was reported by Singh *et al.* (2016) in guava who observed higher canopy spread in widely spacing as compared in closely spaced trees.

4.5.8 Light reduction percentage (cf. Table 44)

Light interception study was conducted from 15 to 24 months after planting at 3 months' intervals and then worked out the light reduction percentage. At all the intervals, significantly higher light reduction percentage was observed with closer spacing (2 m x 1 m). At 15 MAP, significantly higher light reduction percentage was recorded in closer spacing of 2 m x 1 m (15.42) when compared with spacing of 9 m x 3 m (5.75) however, it was at par with rest of the treatments. Similar trend was noticed at 18, 21 and 24 MAP in different intervals. Singh *et al.* (2016) opined that photosynthetically active radiation (PAR) was found to be less in closely spaced trees than medium and widely spaced thus noticing better light penetration with wider spacings at 6.0 x 6.0 m and 3.0 x 6.0 m than the other narrow spaced distances at NS/EW canopy edge and centre of inter and intra row space.

These results are in consonance with that of Pradeep (2015) who reported that wider planting geometry (24 x 5 m²) for *Melia dubia* was significantly superior in terms of its tree height, biomass, bole height, GBH, collar diameter, canopy spread towards north-south and towards east-west, volume and biomass when compared with other narrow planting geometries. These results are in consistent with Kirankumar and Patil (2017) and Patil *et al.* (2017) in which they mentioned that increase in population levels with *Melia dubia* species can cause an increase in total stand volume.

From the present investigation on high density planting of *Melia dubia* for consecutive two years for sole plantation, 2 m x 1 m or 3 m x 1 m or 3 m x 2 m or 4 m x 1 m spacing can be adopted to get maximum timber yield, where as under intercropping system, *Melia dubia* spaced at 9 m x 3 m spacing is most suitable.

Table 44. Canopy spread and light reduction percentage in *Melia dubia* tree at different growth stages under high density planting system

Treatments	Tree canopy spread (m)								Light reduction percentage			
	15 MAP		18 MAP		21 MAP		24 MAP		15 MAP	18 MAP	21 MAP	24 MAP
	N-S	E-W	N-S	E-W	N-S	E-W	N-S	E-W				
T₁ : 2 m x 1 m (5000 trees ha ⁻¹)	0.28	0.31	0.35	0.40	0.54	0.87	0.99	1.05	15.42	18.85	22.22	42.61
T₂ : 2 m x 2 m (2500 trees ha ⁻¹)	0.38	0.43	0.47	0.55	0.73	1.14	1.20	1.74	13.03	15.69	20.52	37.83
T₃ : 3 m x 1 m (3333 trees ha ⁻¹)	0.33	0.38	0.41	0.48	0.64	1.11	1.05	1.46	14.22	17.71	21.27	38.66
T₄ : 3 m x 2 m (1667 trees ha ⁻¹)	0.40	0.45	0.50	0.58	0.78	1.21	1.28	1.82	13.79	17.29	20.34	37.23
T₅ : 4 m x 1 m (2500 trees ha ⁻¹)	0.30	0.35	0.36	0.42	0.53	1.09	1.02	1.39	14.55	17.14	18.64	37.74
T₆ : 4 m x 2 m (1200 trees ha ⁻¹)	0.40	0.46	0.50	0.58	0.78	1.22	1.29	1.77	12.16	13.92	16.22	30.12
T₇ : 9 m x 3 m (370 trees ha ⁻¹)	0.43	0.48	0.53	0.62	0.83	1.39	1.36	1.86	5.75	10.24	13.17	17.63
S.Em.±	0.02	0.03	0.03	0.03	0.04	0.06	0.07	0.11	1.14	1.23	1.35	1.74
C. D. at 5%	0.07	0.07	0.08	0.10	0.13	0.19	0.21	0.34	3.52	3.78	4.15	5.35

MAP: Months after planting

NS: Not significant

N-S: North South direction

E-W: East West direction



Plate 3a: General view of Experiment -IV

Plate 3. Effect of different levels of spacing on growth of *Melia dubia*



Plate 3b. *Melia dubia* with higher plant density 5000 plants ha⁻¹ (2 m x 1 m) at 21 MAP



Plate 3c. *Melia dubia* with higher plant density 3333 plants ha⁻¹ (3 m x 1 m) at 21 MAP

Plate 3. Effect of different levels of spacing on growth of *Melia dubia*



Plate 3d. *Melia dubia* with higher plant density 1667 plants ha⁻¹ (3 m x 2 m) at 21 MAP



Plate 3e. *Melia dubia* with higher plant density 1200 plants ha⁻¹ (4 m x 2 m) at 21 MAP

Plate 3. Effect of different levels of spacing on growth of *Melia dubia*

SUMMARY AND CONCLUSIONS

V. SUMMARY AND CONCLUSIONS

The investigation on “Agronomic manipulations for productivity and income enhancement in *Melia dubia* Cav. based agroforestry system under organic production” was conducted during 2018 and 2019 at University of Agricultural Sciences, Raichur. Investigation consisted of “Survey on performance of *Melia dubia* in agroforestry system on farmers’ field in Kalyana Karnataka region and three field experiments viz., Effect of pre-sowing seed treatment on germination of *Melia dubia* at Biofuel Park, ARS, Tinthani, Performance of foxtail millet as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system on farmer’s field at Santhekellur village of Raichur district and Early growth performance of *Melia dubia* under high density planting system at Biofuel Park, ARS, Tinthani.

Experiment - I: Survey on performance of *Melia dubia* in agroforestry system on farmers’ field in Kalyana Karnataka region

Survey was conducted in Kalyana Karnataka region and data were collected from 38 farmers in six districts with an objective to study the performance of *Melia dubia* in agroforestry system on farmers’ field. Out of 38 respondents selected, 24 respondents comprising of more than 60 per cent were farmers *i.e.*, whose livelihood depends on farming only, while, rest (12 respondents) comprising 28.95 per cent were non-farmers (businessmen). The survey revealed that, with respect to adoption of *Melia dubia*, 63.16 per cent respondents adopted intercrops in between definite row proportion of *Melia dubia*, while, 26.31 per cent respondents cultivated as sole plantation and 10.53 per cent farmers had *Melia dubia* as hedge plantation. Out of 28 respondents who adopted arable crops with *Melia dubia*, 16 respondents adopted horticultural plantation crops like pomegranate, papaya and lime which covered 60.85 per cent of total area while, 5 respondents adopted tree species like sandalwood. In respect of *Melia dubia* plant density under intercropping system with arable crops, 44.74 per cent respondents adopted 501 to 1000 trees per ha, which covered 52.16 per cent total area followed by 28.95 per cent respondents adopted 73 to 500 trees per ha. Only two respondents were in adoption of higher plant density (2001 to 2500 tree ha⁻¹), which covered 5.93 per cent of total area.

The data pertaining to source of information which inspired for adoption of *Melia dubia*, most of respondents gathered the information from TV/You Tube and fellow

farmers, which covered 63.15 per cent each. This was mainly attributed to availability of smart mobiles in the villages.

Data regarding distribution of respondents according to their opinion based on the knowledge they gained for adoption of *Melia dubia* was collected from 38 respondents. Majority of farmers (54.21 %) expressed that they did not know about role of *Melia dubia* for control of pest and diseases, while 39.47 per cent respondents were of the opinion of increase in yield of crops during early stage of tree plantation, 28.95 per cent respondents expressed shade effect, poor germination of crop near vicinity and also reduction in yield of intercrops due to *Melia dubia* plantation at later stage of tree establishment.

Data on distribution of respondents according to their opinion on objectives of *Melia dubia* plantations was categorized into nine classes. The 63.53 per cent of respondents mainly adopted *Melia dubia* to serve as wind breaker in horticulture plantations, followed by 44.74 per cent for improvement of soil fertility, 31.58 per cent of respondents to create shade in pomegranate, papaya and lime while 28.95 per cent of respondents for timber purpose.

Regarding opinion of farmers towards non-adoption of *Melia dubia* in their field, all respondents expressed that they were not willing to grow *Melia dubia* due to market problem. Others problems expressed by the respondents were long gestation period (81.58 %), lack of awareness about cultivation of *Melia dubia* (61.58 %) their small size land holding (55.26 %) and non availability of quality seedlings (47.37 %) at affordable price.

The trees were in the age of the two to eight years old in the selected farmers' field. Average growth indices of *Melia dubia* at the age of two years were 5.35 m in case of tree height, 3.54 m bole height, 15.36 cm collar diameter and 10.80 cm DBH with wood volume of 0.050 m³ plant⁻¹. At the three years' age, on an average, the figures corresponded with tree height, bole height, collar diameter, DBH and wood volume were 5.41 m, 3.88 m, 22.93 cm, 19.19 cm and 0.140 m³ plant⁻¹ respectively. At the age of four years, observations on tree height, bole height, collar diameter, DBH and volume of *Melia dubia* tree ranged from 5.98 to 7.95 m, 4.56 to 4.72 m, 22.26 to 27.15 cm, 17.85 to 23.56 cm and 0.181 to 0.346 m³ plant⁻¹ respectively with an average of 6.81 m, 5.13 m, 24.88 cm, 22.35 cm and 0.201 m³ plant⁻¹ respectively. At the age of five years, average *Melia dubia* tree exhibited tree height of 8.04 m, bole height of 6.29 m, collar diameter of

31.23 cm, DBH of 26.43 cm and wood volume of 0.440 m³ plant⁻¹. While, at the age of sixth year, on an average, the figures corresponded with tree height, bole height, collar diameter, DBH and wood volume were 8.73 m, 6.69 m, 30.27 cm, 30.27 cm and 0.581 m³ plant⁻¹ respectively. Data recorded at the eight years old tree on tree height, bole height, collar diameter, DBH and wood volume corresponded to 11.54 m, 6.89 m, 41.05 cm, 31.08 cm and 0.875 m³ plant⁻¹, respectively.

Estimation of yield from 8th year plantation by considering volume of tree was 0.875 m³ plant⁻¹ was about 803.25 m³ ha⁻¹ and monetary returns around Rs 32,13,000 ha⁻¹ @ Rs. 125 per cubic feet or Rs. 3500 plant⁻¹. In conclusion, it can be noted that growth and volume of *Melia dubia* recorded under irrigated ecosystem (red soils) was higher than that of rainfed ecosystem, thus indicating that the species require enough soil moisture, nutrient and sunlight during its growth particularly during early period.

Experiment - II: Effect of pre-sowing seed treatment on germination of *Melia dubia*

The experiment was conducted for two years during 2018 and 2019 under shadenet at Biofuel Park, ARS, Tinthani. The experiment was laid out in completely randomized design, consisting of eleven treatments. There were eleven treatments comprising seed treatment with cold water, cowdung slurry, biogas slurry and KNO₃ solution for various periods along with control.

Imbibition period and total germination period were significantly lower with seeds soaked in KNO₃ (200 m moles for 24 hrs) solution (35.17 and 66.5 days, respectively), followed by soaking of seeds in cowdung slurry for 12 days (39.0 and 69.5 days, respectively) when compared to all seed soaking treatments. Significantly higher imbibition period (52 days) was observed in control plot.

In pooled data, seeds soaked in KNO₃ (200 m moles for 24 hrs) solution recorded significantly higher seed germination (45.37 %) over all other seed treatments except seeds soaked in cowdung slurry (42.59 %) and biogas slurry (39.81 %). Similarly, significantly higher germination value and germination energy were also observed when seeds were soaked in KNO₃ solution and it was found on par with germination value of seeds soaked in cowdung and biogas slurry for 12 days.

Significantly higher shoot, root and total length of seedlings, collar diameter and number of seedlings were recorded with seeds soaked in cowdung slurry for 12 days than all other treatments except with seeds soaked in biogas slurry for 12 days in pooled analysis. Significantly lower length of seedling was noticed in control plot.

In pooled data, shoot, root and total dry weight of seedling were significantly higher with seeds soaked in cowdung slurry for 12 days when compared with all other treatments, however, it was on par with seeds soaked in cowdung slurry for 8 days, biogas slurry for 8 days and 12 days and KNO₃ solution. Significantly lower dry weight of seedlings was observed in control plot which received seed treatment practice. Significantly higher vigour index (1674) was recorded in the treatment where seeds soaked in cowdung slurry for 12 days followed by seeds soaked in biogas slurry for 12 days (1587) and KNO₃ solution (1464). The control treatment registered significantly lower vigour index (436) over rest of all other treatments.

Experiment-III: Performance of foxtail millet as influenced by organic nutrient management practices in *Melia dubia* based agroforestry system

The experiment was conducted for two years on farmer's field at Santhekallur village of Raichur district which represents Northern Dry Zone of Karnataka (Zone 3). There were eleven treatments with three replications, laid out in completely randomized block design. The treatments consisted of application of no organic manure (control), FYM equivalent to 100 per cent RDN, FYM (50%) + Vermicompost (50 %) and FYM (50 %) + Poultry manure (50 %) equivalent to 100 per cent RDN alone and in combination with foliar spray of 3.0 per cent panchagavya and 5.0 per cent vermiwash at 30 and 45 DAS and foliar spray of 3.0 per cent panchagavya at 30 DAS alternated with 5.0 per cent vermiwash at 45 DAS. All these ten treatments were assessed with *Melia dubia* tree component in comparison with sole foxtail millet with recommended organic nutrient management practices without tree.

Growth parameters namely plant height, number of leaves, number of tillers, dry matter accumulation and its distribution per plant were significantly higher under sole foxtail millet with without tree association when compared with foxtail millet with tree association under various organic manurial treatments in both the years and pooled data. In *Melia dubia* based agroforestry system with foxtail millet crop, application of FYM +

poultry manure + panchagavya alternated with vermiwash spray followed by FYM + vermicompost + panchagavya alternated with vermiwash spray recorded significantly higher all growth parameters of foxtail millet when compared with no organic manurial treatment. Similar trend was followed with respect to leaf area, leaf area index, absolute growth rate, crop growth rate and relative growth rate.

Yield parameters like ear head length, ear head weight and test weight were significantly higher under sole foxtail millet without tree association when compared with foxtail millet with tree association under various organic manurial treatments in both the years and pooled data. In *Melia dubia* based agroforestry system, significantly higher ear head length, ear head weight and test weight were recorded with application of FYM + poultry manure + panchagavya alternated with vermiwash spray while no organic manures applied treatment resulted in lower values in these parameters.

Sole foxtail millet grown organically without tree component recorded significantly higher grain yield (1656 kg ha^{-1}) when compared with all other treatments with tree association in agroforestry system in pooled data. The mean grain yield in former treatment was 28 per cent more than the yield obtained in various treatments of agroforestry system with *Melia dubia* tree. Among the treatments in agroforestry system, FYM + poultry manure + panchagavya alternated with vermiwash imposed treatment showed its significant superiority (1487 kg ha^{-1}) over all other organic manurial treatments except FYM + vermicompost + panchagavya alternated with vermiwash spray (1440 kg ha^{-1}), FYM + poultry manure + panchagavya (1412 kg ha^{-1}), FYM + vermicompost + panchagavya (1406 kg ha^{-1}), FYM + poultry manure + vermiwash (1403 kg ha^{-1}) which in turn were on par with each other. All organic manurial treatments resulted in significantly higher grain yield over the treatment which received no organic manure application (801 kg ha^{-1}). Similar trend was also followed in straw yield. There was no significant difference in harvest index due to different treatments.

In pooled data, nitrogen, phosphorus and potassium uptake by foxtail millet at harvest were significantly higher in sole foxtail millet with recommended organic nutrient management practices without tree component (45.67 , 12.77 and 55.90 kg ha^{-1} , respectively) when compared with all the treatments with tree association in agroforestry system compared to all other treatments. No organic manurial treatment recorded

significantly lower nitrogen, phosphorous and potassium uptake (10.55, 4.95 and 22.18 kg ha⁻¹, respectively) at harvest of the crop.

With respect to soil properties, there was no significant difference in soil pH, electric conductivity and soil organic carbon content due to different treatments in both the years and in pooled data. While, with tree association in agroforestry system, available soil nitrogen, phosphorus and potassium were significantly higher by application of FYM + poultry manure + panchagavya alternated with vermiwash spray (242.80, 27.60 and 311.52 kg ha⁻¹, respectively) followed by application of FYM + poultry manure + vermiwash spray (235.17, 24.93 and 288.61 kg ha⁻¹, respectively) which in turn showed significant superiority over no organic manurial treatment, application of FYM and FYM + vermiwash spray. Soil nutrient availability in the treatment of without tree association found to be lower than all the organic nutrient management practices in tree association except no organic manurial treatment which resulted in lower soil available nitrogen, phosphorous and potassium (198.53, 8.55 and 187.21 kg ha⁻¹, respectively) after harvest of the crop.

Pertaining to microbial population, at 60 DAS, in pooled data, FYM + poultry manure + panchagavya alternated with vermiwash spray recorded significantly higher bacterial (47.11 10⁶ CFU g⁻¹ of soil), fungal (33.80 10⁴ CFU g⁻¹ of soil) and actinomycetes population (35.14 10³ CFU g⁻¹ of soil) when compared with no organic manurial treatment (28.45 10⁶ CFU g⁻¹ of soil, 20.64 10⁴ CFU g⁻¹ of soil and 22.64 10³ CFU g⁻¹ of soil, respectively). Similar trend was followed at harvest with decrease in population of all above microorganisms

Regarding enzyme activities in the soil as influenced of organic nutrient management practices, at 60 DAS, in pooled data, with tree association, significantly higher alkaline phosphatase and de-hydrogenase activities were found with application of FYM + poultry manure + panchagavya alternated with vermiwash (124.38 µg PNP cfu g⁻¹ soil hr⁻¹ and 44.78 µg TPF formed g⁻¹ soil day⁻¹ respectively) when compared with no organic manures plot (77.95 µg PNP cfu g⁻¹ soil hr⁻¹ and 26.94 µg TPF formed g⁻¹ soil day⁻¹, respectively).

Tree properties viz., tree height, bole height, girth at breast height, diameter at breast height, collar diameter were maximum with application of FYM + poultry manure

+ panchagavya alternated with vermiwash followed by FYM + poultry manure + panchagavya spray, while lower values in these parameters were with no organic manurial treatment.

Significantly lower light reduction percentage was exerted in sole foxtail millet grown organically without tree component (20.98 %) when compared with all the treatments with tree association in agroforestry system (32.46 to 35.06 %). While, *Melia dubia* tree wood volume was highest being recorded with application of FYM + poultry manure + panchagavya (61.48 t ha⁻¹) followed by FYM + poultry manure + panchagavya alternated with vermiwash (61.04 t ha⁻¹). No organic manurial treatment recorded lowest wood volume (49.99 t ha⁻¹).

Significantly higher carbon stock in biomass was observed with the application of FYM + poultry manure + panchagavya (22.03 t ha⁻¹) followed by FYM + poultry manure + panchagavya alternated with vermiwash spray (21.97 t ha⁻¹) while lower biomass was recorded with no organic manurial treatment (17.34 t ha⁻¹) in agroforestry system. Significantly higher carbon sequestration was observed with the application of FYM + poultry manure + panchagavya (80.87 t ha⁻¹) while lowest was with no organic manures treated plot (63.64 t ha⁻¹) with tree association in *Melia dubia* based agroforestry system.

The economic analysis of foxtail millet cultivation alone indicated that, significantly higher net returns (Rs. 34002 ha⁻¹) and benefit cost ratio (2.50) were realized in sole foxtail millet cultivation with recommended organic nutrient sources without tree association when compared with crop in association with *Melia dubia* tree (Rs 13,978 to 28,631 ha⁻¹ and 1.76 to 2.31, respectively). In agroforestry system, application of FYM + poultry manure + panchagavya alternated with vermiwash spray recorded significantly higher net returns and benefit cost ratio (Rs. 28,631 ha⁻¹ and 2.31, respectively) when compared with all the treatments except FYM + poultry manure + vermiwash spray (Rs. 26402 ha⁻¹) and FYM + vermicompost + panchagavya alternated with vermiwash spray (Rs. 26205 ha⁻¹). No organic manurial treatment recorded significantly lower net returns (Rs. 13,978 ha⁻¹) compared to all treatments except FYM (Rs. 16,337 ha⁻¹).

In system economics analysis (Foxtail millet + tree), crop associated with tree with application of and FYM + poultry manure + panchagavya alternated with vermiwash spray and FYM + poultry manure + panchagavya recorded significantly higher net returns

(Rs 3,21,056 ha⁻¹ and 3,20,715 ha⁻¹ respectively) and benefit cost ratio (4.81 and 4.78, respectively) over all other treatments. Foxtail millet cultivated organically in open condition without tree component recorded significantly lower net returns (Rs. 37,742 ha⁻¹) and benefit cost ratio (4.16).

Experiment - IV: Early growth performance of *Melia dubia* under high density planting system

Study on early growth performance of *Melia dubia* under high density planting system was carried out for two years during 2018-19 and 2019-20 at Biofuel Park, ARS, Tinthani with an objective to estimate growth, volume and optimum productivity of the species in relation to different planting densities at three months' time intervals. The experiment was laid out in completely randomized block design comprising seven treatments with 3 replications. The treatment comprised of varied spacing levels with different plant densities, 2 m x 1m (5000 trees ha⁻¹), 2 m x 2 m (2500 trees ha⁻¹), 3 m x 1m (3333 trees ha⁻¹), 3 m x 2m (1667 trees ha⁻¹), 4 m x 1 m (2500 trees ha⁻¹), 4 m x 2 m (1200 trees ha⁻¹) and 9 m x 3 m (370 trees ha⁻¹).

The height of *Melia dubia* tree did not differ significantly due to varied spacing levels at 3, 6, 9 and 12 months after planting (MAP), while there was significant difference at 15, 18, 21 and 24 MAP. At 15 MAP, significantly taller plants were recorded with 9 m x 3 m spacing (3.67 m) and it was on par with 2 m x 1 m (3.17 m) and 3 m x 1 m (3.11 m). The spacing of 4 m x 2 m resulted in shorter plants (2.72 m). All other treatments were intermediary. Similar trend was also seen at 18, 21 and 24 MAP. At the end of experiment (24 MAP), on an average 120.32 per cent increase in tree height from 15 to 24 months after planting was observed.

At 15, 18, 21 and 24 MAP, significantly higher bole height of *Melia dubia* tree was recorded with 9 m x 3 m (2.87 m, 3.65 m, 4.09 m and 5.39 m respectively) over all other treatments except 2 m x 1 m (2.47 m, 3.40 m, 3.89 m and 4.99 m respectively) and 3 m x 1 m (2.43 m, 3.32 m, 3.60 m and 4.62 m respectively) spacings. The lower bole height was found with 4 m x 2 m spacings at all the growth stages (1.61 m, 2.72 m, 2.64 m and 4.24 m respectively).

At all the growth stages studied (15, 18, 21 and 24 MAP), girth at breast height (GBH), diameter at breast height (DBH) and collar diameter were significantly higher

under spacing of 9 m x 3 m with 370 trees ha⁻¹. While the lower values with these characters were seen with closer spacing of 2 m x 1 m with 5000 plants ha⁻¹. The effect of other treatments was intermediary.

At 24 MAP, closer spacing of 2 m x 1 m with 5000 plants ha⁻¹ recorded significantly higher volume of tree (1171.81 m³ ha⁻¹) over all other treatments. The effect of different levels of spacing on tree volume was in the order of 2 m x 1 m (1171.81 m³ ha⁻¹), 4 m x 1 m (806.27 m³ ha⁻¹), 2 m x 2 m (755.69 m³ ha⁻¹), 3 m x 2 m (736.49 m³ ha⁻¹), 3 m x 1 m (723.20 m³ ha⁻¹), 4 m x 2 m (621.98 m³ ha⁻¹) and 9 m x 3 m (287.67 m³ ha⁻¹). At all the intervals, significantly higher light reduction percentage was observed with closer spacing (2 m x 1 m). At 15 MAP, significantly higher light reduction percentage was recorded in closer spacing of 2 m x 1 m (15.42) when compared to spacing with 9 m x 3 m (5.75). Similar trend was followed in different intervals. At 18, 21 and 24 MAP, closer spacing of 2 m x 1 m recorded significantly higher light reduction percentage when compared to 9 m x 3 m and 4 m x 2 m spacings.

From the present investigation on “Agronomic manipulations for productivity and income enhancement in *Melia dubia* Cav. based agroforestry system under organic production” the following conclusions can be drawn.

1. *Melia dubia*, a multipurpose fast growing tree species with a short rotation of 10-12 years, is well suited to Kalyana Karnataka region. The survey made in the locality depicted its well adaptability and suitability owing to prevailing optimum soil and climatic conditions to cultivate the species either alone as sole crop under high density planting system or with crops in agroforestry system.
2. Seed germination is a major hurdle in propagation of good quality seedlings of *Melia dubia* at required time due to its hard seed coat. To obtain higher percentage of germination and healthy seedlings in nursery, pre-sowing seed treatments viz., soaking seeds in KNO₃ solution (200 m moles for 24 hrs) or cowdung slurry for 12 days or biogas slurry for 12 days could be followed. These practices are low cost, easily accessible and eco-friendly technologies for timely production of quality seedlings.
3. Based on the results of the two years (24 months), higher economic yield (wood volume) of *Melia dubia* under sole plantation could be obtained with the plant density

of 5000 plants ha⁻¹ by adopting 2 m x 1 m spacing. The spacings of 2 m x 2 m with 2500 plants ha⁻¹, 3 m x 1 m with 3333 plants ha⁻¹, 3 m x 2 m with 1667 plants ha⁻¹ and 4 m x 1 m with 2500 plants ha⁻¹ showed promising in irrigated conditions during early stage of *Melia dubia* tree establishment under sole cropping. The spacing of 9 m x 3 m with 370 plants ha⁻¹ is most feasible for growing intercrops in agroforestry system.

4. For higher and sustainable system productivity and income in agroforestry practice consisting of foxtail millet with *Melia dubia* plantation spaced at 9 m x 3 m apart, combined application of FYM (50 %) + poultry manure (50 %) equivalent to 100 % recommended 'N' along with foliar spray of 3 per cent panchagavya at 30 and 45 DAS or foliar spray of 3% panchagavya at 30 DAS alternated with 5 per cent vermiwash at 45 DAS could be advised under organic production system. These practices enhanced the nutrient availability and soil biological environment at higher levels in the agroforestry system.
5. The present study highlights, *Melia dubia* + foxtail millet agroforestry system as a better option than sole agricultural cropping. The combination of crop with tree in the study led to higher biomass and carbon sequestration which is of positive benefit in mitigating climate change and maintaining ecological balance.

Future line of work

- Other possible pre-sowing seed treatments can be explored to enhance the germination per cent beyond 45 per cent in *Melia dubia* tree species.
- A long term field investigation needs to be conducted in dryland and irrigated ecosystem to ascertain the benefits of different levels of nutrients substitution through organic manures and or liquid manures on yield, quality, soil health and sustainability of arable crops and their residual effect on succeeding crop in *Melia dubia* based agroforestry system.
- Screening of different crops of various types for their suitability in *Melia dubia* based agroforestry system.
- Long term studies on effect of different levels of spacing on performance of *Melia dubia* need to be studied in different ecosystem.

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VI. REFERENCES

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APPENDICES

APPENDIX – Ia

Questionnaire

Survey on performance of *Melia dubia* on farmer's field in Kalyana Karnataka region

Name		Village		Hobli & Taluka												
Total area		Irrigated		Rainfed												
Soil type																
Area under <i>Melia dubia</i>		No of trees/ha		Year of plantation												
Sole		Inter crop														
Spacing																
Area under other trees																
Insect incidence & Control measures																
Disease incidence & Control measures																
Multi use																
Benefits																
Pest control																
Disease control																
Ill effect	Yes	NO	Yes	NO	Yes	NO	Yes	NO	Yes	NO	Yes	NO	Yes	NO	Yes	NO
	I year		II year		III year		IV year		V year		VI year		VII year		VIII year	
Shade																
Poor germination of crops near vicinity																
Low moisture																
Difficulty in agril operation due to rooting																
Yield																
Constraints in adoption																
Does your family size affect your tree planting options: (1) No (2) Yes																
Occupation? (1) Employed (2) Farmer (3) Civil Servant/Teacher (4) Business Man/Woman (5) Other																

I. Types of intercrops adopted

Sl.No	Inter crops	Mark	Area in ha
1	<i>Melia dubia</i> + Redgram		
2	<i>Melia dubia</i> + Cotton		
3	<i>Melia dubia</i> + Maize		
4	<i>Melia dubia</i> + Millets		
5	<i>Melia dubia</i> + Sunflower		
6	<i>Melia dubia</i> + Fodder crops		
7	<i>Melia dubia</i> + Vegetables		
8	<i>Melia dubia</i> + Floriculture		
9	<i>Melia dubia</i> + Plantation crops		
10	<i>Melia dubia</i> fallow		

II. Source of information for adoption of *Melia dubia* in agroforestry system

Sl.No	Particulars	Mark
1	Radio	
2	TV	
3	News paper/Magazines	
4	Fellow farmer	
5	Inherited from parents	
6	Agri/Forest departments	
7	Scientist (UAS/KVK/AEEC)	
8	NGO's	
9	Social media (SMS/Whats app)	

III. Farmers gained knowledge regarding adoption of *Melia dubia* based agroforestry system

Sl.No	Inter crops	Mark
1	Soil and water conservation	
2	Rainfall attraction	
3	Enhancement of soil fertility	
4	Shade or wind break purpose	
5	To get additional income	
6	Wood/timber purpose	
7	Fodder purpose	

IV. Farmer opinion about non adoption of *Melia dubia* plantation

Sl.No	Particulars	Mark
1	Lack of awareness about <i>Melia dubia</i>	
2	Lack of extension service from department	
3	Small size land holdings	
4	Non availability of seedlings	
5	Hindering farm operation	
6	Shade effect to neighbouring field	
7	Decrease in crop yields due to shade	
8	Long gestation period	
9	Market problem	
10	It may attract pest and diseases	

V. Farmers opinion on objectives of *Melia dubia* plantation

Sl.No	Particulars	Mark
1	Field boundary	
2	Act as a fence	
3	Fodder	
4	Erosion control	
5	Timber purpose	
6	Fuel wood	
7	Shade	
8	Wind breaker	
9	Soil fertility improvement	
10	Control of pest and diseases	

VI. Plant growth parameters

Sl.No	Particulars	1 st plant	2 nd plant	3 rd plant	4 th plant	5 th plant
1	Plant height (cm)					
2	Bole height (cm)					
3	DBH (cm)					
4	Collar diameter (cm)					

APPENDIX Ib

Basic information of respondents towards adoption of *Melia dubia*

Sl.No	Name	Village	Taluka	District	Occupation	Land holding (ha)	Area under <i>Melia</i>	Year of planting	How old-years	No of plants ha ⁻¹	Irrigated (ha)	Rainfed (ha)	Spacing (m ²)	Sole	Intercrop
F ₁	Manjunath	Manvi	Manvi	Raichur	Farmer	3.6	2.2	2017	2	781	2.2	-	4.0 x 2.4	-	Sandal wood
F ₂	Narayanrao	Hulsogod	Chinchili	Kalburgi	Business	1	1	2017	2	73	-	1.0	30 x 4.5	Hedge	-
F ₃	Sharanappa	Sannur	Chittapur	Kalburgi	Employ	2.4	2.4	2017	2	494	-	2.4	4.5 x 4.5	Sole	-
F ₄	Yuvarajshetty	Sannur	Chittapur	Kalburgi	Employ	1.2	1.2	2017	2	494	-	1.2	4.5 x 4.6	Sole	-
F ₅	Asim Patel	Rajol	Basavkalyan	Bidar	Farmer	1.6	0.8	2017	2	545	-	0.8	6.0 x 3.0	-	Sandal wood
F ₆	Hanumantray	Hunsagi	Hunsagi	Yadgir	Farmer	2.4	1	2017	2	520	1	-	9.1 x 2.1	Hedge	Papaya, chilli
F ₇	Devappa Y	Isampur	Hunsagi	Yadgir	Farmer	1.6	1.6	2017	2	332	1.6	-	9.1 x 3.3	Hedge	Papaya, Banana
F ₈	Gopal R	Isampur	Hunsagi	Yadgir	Farmer	2	2	2017	2	332	2.0	-	9.12 x 3.3	-	Chilli
F ₉	Shantagouda	Channapattan	Hunsagi	Yadgir	Farmer	2	2	2017	2	1111	2.0	-	3.0 x 3.0	-	Pomegranate papaya
F ₁₀	Adappa	Kodihal	Maski	Raichur	Farmer	2.4	0.4	2017	2	1111	0.4	-	3.0 x 3.0	Sole	-
F ₁₁	Hanumanth G.	Kampli	Koppal	Koppal	Farmer	42.4	4	2017	2	918	4.0	-	3.3x3.3	Sole	-
F ₁₂	Bhoomreddy	Neeralkeri	Lingsugur	Raichur	Business	4	2	2017	2	1923	2.0	-	2.6 x 2.0	-	Pomegranate
F ₁₃	Basangouda	Hulkal	Shahapur	Yadgir	Farmer	2.4	0.4	2017	2	1515	0.4	-	3.3 x 3.0	-	Medicinal plants
F ₁₄	Vijendrakumar	Bennur	Chittapur	Kalburgi	Employ	4	0.8	2016	3	495	-	0.8	4.5 x 4.6	Sole	-
F ₁₅	Raj	Khanapur	Basavkalyan	Bidar	Farmer	0.8	0.8	2016	3	545	0.8	-	6.1 x3.01	-	Sandalwood
F ₁₆	Nagaraj	Mogal	Chittapur	Kalburgi	Farmer	2	2	2016	3	1157	2	-	3.6 x 2.4	-	Lime

F ₁₇	Devappa G.	Nagarahal	Lingsugur	Raichur	Farmer	4.8	1.68	2016	3	333	1.68	-	6.0 x 5.0	Sole	-
F ₁₈	Shamraya	Advibhavi	Lingsugur	Raichur	Business	6	2.4	2016	3	277	2.4	-	6.0 x 6.0	-	Pomegranate
F ₁₉	Rachappa	Huligudda	Lingsugur	Raichur	Farmer	1	1	2016	3	333	1.0	-	10 x 3.0	-	Marigold and vegetables
F ₂₀	Devappa V.	Algundi	Koppal	Koppal	Business	8	2	2016	3	918	2.0	-	3.3 x 3.3	-	Vegetable
F ₂₁	Hemaraj S.	Algundi	Koppal	Koppal	Business	16	6.4	2016	6.4	555	6.4	-	5.4 x 3.3	-	Pigeonpea
F ₂₂	Sharanappa	Chikkhesuru	Lingsugur	Raichur	Farmer	2.4	0.8	2015	4	1250	0.8	-	4.0 x 3.0	Sole	-
F ₂₃	Malleshgouda	Mattur	Maski	Raichur	Business	10	0.8	2015	4	833	0.8	-	4.0 x 3.0	-	Mulberry
F ₂₄	Siddalingayya	MKarlkunte	Maski	Raichur	Farmer	2.4	0.8	2015	4	833	0.8	-	4.0 x 3.0	-	Chilli
F ₂₅	Siddanagouda	K. Lingsur	Lingsugur	Raichur	Business	10	3.2	2015	4	1736	3.2	-	2.4 x 2.4	-	Pomegranate
F ₂₆	Sharanappa	Sumbad	Jewargi	Kalburgi	Farmer	3.2	2	2015	4	918	2.0	-	3.3 x 3.3	-	Sandalwood
F ₂₇	Prakash	Goga	Basavkalyan	Bidar	Farmer	1.6	0.4	2015	4	917	0.4	-	4.5 x 2.4	-	Mango
F ₂₈	Veerareddy	Chikkhesuru	Lingsugur	Raichur	Farmer	3.2	0.8	2014	5	2500	0.8	-	2.0 x 2.0	Sole	-
F ₂₉	Shambanna	K. Lingsuur	Lingsugur	Raichur	Business	12.0	3.2	2014	5	2314	3.2	-	2.4 x 1.8	-	Pomegranate
F ₃₀	Shivakumar	Gudihal	Lingsugur	Raichur	Farmer	15.2	0.8	2014	5	1111	0.8	-	3.0 x 3.0	-	Mixed horticulture
F ₃₁	Shivakumar	Malla	Shorapur	Yadgir	Farmer	3.2	2.0	2014	5	918	2.0	-	3.3 x 3.3	-	Lime
F ₃₂	Channabasapp	Khanahosalli	Kudligi	Ballari	Farmer	3.0	3.0	2014	5	918	3.0	-	3.3 x 3.3	-	Lime, Sapota
F ₃₃	Udaykumar	Ankusdoddi	Maski	Raichur	Business	4.8	1.2	2013	6	333	1.2	-	6.0 x 5.0	-	Guava
F ₃₄	Rajani	Gorebal	Lingsugur	Raichur	Business	3.2	2.4	2013	6	862	2.4	-	4.8 x 2.4	-	Pomegranate
F ₃₅	Chandramm	Santhekellur	Maski	Raichur	Farmer	4.8	1.0	2013	6	370	1.0	-	9.0 x 3.0	-	Pigeonpea
F ₃₆	Ramaswamy	Pujarhalli	Kudligi	Ballari	Farmer	2.0	1.4	2013	6	918	0	1.4	3.3 x 3.3	Sole	-
F ₃₇	Devareddy	Eachnal	Lingsugur	Raichur	Business	8.8	3.2	2013	6	918	3.2	-	3.3 x 3.4	Hedge	Pomegranate
F ₃₈	Boranna	K.B.Hatti	Kudligi	Ballari	Farmer	3.6	2.4	2011	8	918	2.4	-	3.3 x 3.4	Sole	-
					Total	205.0	67.48				59.88	7.60			

APPENDIX – II

Price list of inputs and outputs for the year 2018

Sl. No	Inputs	Unit	Price (Rs)
A. Inputs			
1	Seed material		
	a. Foxtail millet seeds (HN-46)	kg	35
	b. <i>Melia dubia</i> seedling	Per seedling	5
2	Organic inputs		
	a. FYM	kg	1.0
	b. Vermocompost	kg	3.5
	c. Poultry manure	kg	5.0
	d. Panchagavya	Litre	40
	e. Vermiwash	Litre	2
3	Labour and implements		
	a. Men	Rs. per day	300
	b. Women	Rs. per day	200
	c. Bullock pair	Rs. per day	500
	d. Tractor with men	Rs. per hour	800
B. Outputs			
	a. Grain yield of foxtail millet	kg	28.5
	b. Straw yield of foxtail millet	kg	2.5

APPENDIX – III

Price list of inputs and outputs for the year 2019

Sl. No	Inputs	Unit	Price (Rs)
B. Inputs			
1	Seed material		
	a. Foxtail millet seeds (HN-46)	kg	35
2	Organic inputs		
	a. FYM	kg	1.0
	b. Vermocompost	kg	3.5
	c. Poultry manure	kg	5.0
	d. Panchagavya	Litre	40
	e. Vermiwash	Litre	2
3	Labour and implements		
	e. Men	Rs. per day	300
	f. Women	Rs. per day	200
	g. Bullock pair	Rs. per day	500
	h. Tractor with men	Rs. per hour	800
B. Outputs			
	a. Grain yield of foxtail millet	kg	30.5
	b. Straw yield of foxtail millet	kg	2.5
	c. Wood value of <i>Melia dubia</i>	Tonne	5762

APPENDIX IV

Nutrient composition of organic manures

Sl.No	Organic manure	Nutrient composition		
		Nitrogen	Phosphorus	Potassium
1	FYM (%)	0.42	0.21	0.45
2	Vermicompost (%)	1.52	0.65	1.25
3	Poultry manure (%)	2.82	1.73	1.37
4	Vermiwash (%)	0.005	0.0025	0.063
5	Panchagavya (ppm)	795	134	193

AGRONOMIC MANIPULATIONS FOR PRODUCTIVITY AND INCOME ENHANCEMENT IN *Melia dubia* Cav. BASED AGROFORESTRY SYSTEM UNDER ORGANIC PRODUCTION

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2020

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ABSTRACT

The experiment on “Agronomic manipulations for productivity and income enhancement in *Melia dubia* based agroforestry system under organic production” was conducted during 2018 and 2019 at University of Agricultural Sciences, Raichur.

Survey was carried out on adoption of *Melia dubia* in Kalyana Karnataka region. The data collected from 38 farmers indicated that 63.16 per cent respondents adopted intercrops in between definite row proportion of *Melia dubia*, while, 26.31 per cent respondents cultivated as sole plantation. Most of respondents gathered information from TV/You Tube and fellow farmers.

In pre-sowing seed treatment study in *Melia dubia*, seeds soaked in KNO₃ solution (200 m moles for 24 hours) recorded higher seed germination percentage (45.37) followed by soaking in cowdung slurry for 12 days (42.59) and were on par in respect of total length, collar diameter, total dry weight and vigour index of seedlings as compared to all other treatments.

In an organic manurial experiment, sole foxtail millet without tree component with recommended organic manures recorded significantly higher grain yield (1656 kg ha⁻¹) than all other the treatments in agroforestry system. With tree association, FYM (50%) + poultry manure (50%) equivalent to recommended N along with foliar spray of panchagavya (3%) at 30 DAS alternated with vermiwash (5%) at 45 DAS recorded significantly higher grain yield (1487 kg ha⁻¹) over control. This treatment also resulted in significant improvement in growth and yield parameters, soil available NPK, microbial population and carbon sequestration. The system economic analysis showed that crop associated with tree with application of FYM + poultry manure + panchagavya alternated with vermiwash and FYM + poultry manure + panchagavya recorded significantly higher net returns and B: C ratio over all other treatments.

Study on early growth performance of *Melia dubia* upto 24 MAP under high density planting system showed that significantly higher tree height, GBH, DBH and collar diameter were recorded at 370 trees ha⁻¹ (9 m x 3 m) compared to other treatments. This spacing can be adopted under intercropping system.