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Research Article

Assessment of compatibility of intercrops in *Dalbergia sissoo* based Hortisilvicultural system in Mondipatty, Manapparai block of Trichy district, Tamil Nadu

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Abstract
Attention to intercropping for sustainable agriculture is increasing, and scientific studies on intercropping have also grown in recent years. Agroforestry Systems, which combine annual crops with trees, are used widely in semiarid regions to reduce wind erosion and improve the efficiency of resources such as water and nutrients. Field experiments were conducted at Tamil Nadu Newsprint and Papers Limited Farm, Mondipatty, Tamil Nadu, to study the compatibility of intercropping systems in the *Dalbergia sissoo*-based Horti-silvicultural system for two years during 2016 and 2017. The experiments were conducted in a split-plot design with four replications.The main plot treatments were M_1: Cassava M_2:Chillies and the subplot treatments were five nutrient management packages *viz.,* S_1: Untreated control, S_2: 100 % Recommended Dose of Fertilizers (Cassava: 90: 90: 240 and Chillies: 60: 80: 80),S_3: 125 % Recommended Dose of Fertilizers (Cassava: 112.5: 112.5: 300 and Chillies: 75: 100: 100), S_4:150 % (Cassava: 135: 135: 360 and Chillies: 90: 120: 120) Recommended Dose of Fertilizers, S_5: Soil Test Crop Response studies - Integrated Plant Nutrient Supply System -based recommendation (as per soil test value). The results indicated that the Horti-Silvicultural system of growing Cassava and Chillies along with *D. sissoo* performed well. It was observed that statistically significant ($p \leq 0.05$) higher yields of 17.8 tha^{-1} and 1.6 tha^{-1} were recorded in Cassava and Chillies, respectively, in treatment S_5, where the fertilizer was applied based on the Soil Test Crop Response studies - Integrated Plant Nutrient Supply System. In addition, the soil fertility status was also sustained in this plot. The fertilizers applied to the intercrops have contributed to the nutrient requirement of the tree crop and thereby reduced the cost of cultivation in the agroforestry system.

Keywords: Agroforestry, Chilli, Cassava, *Dalbergia sissoo,* Soil fertility, Soil Test Crop Response studies - Integrated Plant Nutrient Supply System

INTRODUCTION

Agroforestry (AF) is the management and integration of trees, crops and/or livestock on the same land for productive agriculture (Jose, 2011) in addition to playing a significant role in sustaining the agricultural ecosystem (Schroth and da Mota, 2013). Agroforestry is a popular land use system in many countries worldwide to protect the land from various levels of land degradation. Studies from different dimensions show that agroforestry has the potential to check soil erosion to some extent, reduce soil salinity, acidity, and desertification and increase the soil fertility level (Sivakumar *et al.* 2019). Agroforestry and intercropping practices emphasize the interaction between different plant species. Various studies have highlighted substantial benefits of the agroforestry system and suggested that by adopting this system, both economic and environmental gains can be reaped, producing more output and being more sustainable than mono-crops.

Agroforestry is a medium and a combination of agricultural- and forestry-based technologies that create integrated, diverse and productive land use systems (Garrity and Agus, 2000). It is multifunctional and has many advantages, including conservation of biodiversity, enrichment of soil health (Udawatta *et al*., 2008), sequestration of soil and biomass carbon (Nair *et al*., 2009) and increase in food production and ultimately improvement in resource use efficiency (Munz *et al*., 2014). In addition, AF systems provide ecological services and environmental benefits by reducing soil, wind erosion and desertification (Branca *et al*., 2013). The yield and water use efficiency of apricot agroforestry with annual crops such as millet, peanut and sweet potato were higher than those of sole stands, especially when a legume crop (peanut) or a C4 crop (millet) was used (Bai *et al*., 2016). The role of agroforestry in soil conservation, bioamelioration and climate moderation is mostly acclaimed and one of the compelling reasons for cultivating trees on farm lands. Agroforestry is known to have the potential to mitigate climate change through micro climate moderation and natural resource conservation in the short run and through C sequestration in the long run (Ram Newaj *et al*., 2014). Agroforestry is one of the Good Agricultural Practices (GAP), which has the potential as a climate adaptation strategy for any agricultural production system. This might be due to the shading or intercropping effect with other crops. This is possibly due to the positive impact on decreasing the atmospheric temperature and PAR (photosynthetic active radiation). These factors will produce the required microclimate, which will have a positive impact on the growth and yield of the crops and enhance the quality. In addition, this agroforestry system provides socioeconomic and ecological benefits (Nesper *et al*. 2017), the possibility of higher and steady income from both agricultural/horticultural crops and agroforestry (Jezeer *et al*. 2019) and the benefits accrued through ecosystem services. It improves water quality and, beyond all, conserves soil diversity, organic matter retention, and sustains soil health (Meylan *et al*., 2017).

Application of fertilizer in huge quantities by farmers to the soil without testing the soil causes deleterious effects on both the soil and crop. In some cases where the requirement of the crop is greater but the farmers are reluctant to apply the fertilizers, the crop loss is more due to the deficiency of the nutrients. Farmers are experiencing a declining response to N and P due to the omission of other essential nutrients in their fertilizer schedule (Singh *et al*., 2008).

Ramamoorthy *et al.* (1967) established a theoretical basis and experimental technique, “a targeted yield approach” that recommends balanced fertilization considering the available nutrient status in the soil and the crop needs. It also evades the effect of soil heterogeneity, management practices and climatic conditions on the response behavior of crops through available soil nutrients and supplementary nutrients applied through fertilizers.

The nutrient management practice through the soil test crop response (STCR-IPNS) approach and integrated plant nutrient supply system is unique, indicating that the soil test-based fertilizer dose can achieve higher yield and good management practices. The STCR-IPNS -based fertilizer prescription equations were tested in different parts of the country. The frontline demonstration trials conducted throughout the country showed that soil test-based fertilizer application helps obtain higher response ratios over a wide range of agro-ecological regions (Dey and Srivastava, 2013).

The STCR technology showed higher yield than the farmer’s practice. Adopting this technology increased the yield of hybrid rice (6444) and improved rice variety over the farmer’s practice by 11.7 and 13.9 per cent, respectively (Chaubey *et al*.2015). Nutrient application through the STCR approach was superior to the other approaches in achieving higher vegetative and productivity of egg plants towards higher yield and benefit. The performance of egg plants for sustaining the soil fertility status through balanced nutrition was achieved in the STCR approach (Basavaraja *et al.,* 2019). A review of the literature suggests a lack of information on the combined study of agroforestry and horticultural crops with STCR-IPNS-based systems.

To substantiate the benefits of intercropping in agroforestry systems and to assess the nutrient management techniques for enhancing crop productivity and to enumerate the changes in the soil fertility status of the system, the present investigation used *Dalbergia sissoo* as the main crop and two horticulture crops, Cassava (*Manihot esculenta)* and Chillies (*Capsicum annum),* as intercrops. These kinds of models fall under the Horti silvicultural system. *D. sissoo* is a nitrogen-fixing leguminous tree crop. It is also called the Indian Rose wood tree (or) Sisham in North India. It is a timber yielding tree and is also used as a pulpwood tree. In this study, an attempt was made with a STCR-IPNS-based nutrient management system on *D. sissoo* plantations intercropped with Cassava and chilies. The fertilizer doses are tailored to the requirements of specific yield targets of Cassava and Chillies, taking into account the soil available nutrients.

MATERIALS AND METHODS

Field experiments were conducted at Tamil Nadu News Print Limited (TNPL) farm, Mondipatty of Manapparai block of Trichy district during the years 2016 and 2017 with geo-coordinates of latitude: 10°41'17" N and longitude: 78°26'7"E to study the compatibility of intercrops in *D. sissoo*-based Hortisilvicultural system. The experiment was laid out in a split-plot design with four replications. The intercrops were raised in the field where the tree crop, *D. sissoo* had been already established at a spacing of 4 m x 4 m. The treatments comprised of two main plot treatments *viz.,* M_1: Cassava, M_2: Chillies and the Sub plot treatments were five nutrient management packages *viz.,* S_1: Untreated control, S_2: 100 % Recommended Dose of Fertilizers (RDF) (Cassava: 90: 90: 240 and Chillies**:** 60: 80: 80) S_3: 125 % Recommended Dose of Fertilizers (RDF) (Cassava: 112.5: 112.5: 300 and Chillies: 75: 100: 100), S_4: 150 % Recommended Dose of Fertilizers (RDF)(Cassava: 135: 135: 360 and Chillies: 90: 120: 120),S_5: Soil Test Crop Response recommendations – Integrated Plant Nutrient supply (STCR – IPNS recommendation) (as per soil test value). The fertilizers for treatment S_5 were applied based on the STCR-IPNS equations computed in Tamil Nadu *viz.,* Cassava, FN = 0.560 T – 0.61 SN – 0.81 ON; FP_2O_5 = 0.353 T – 1.80 SP – 0.53 OP and FK_2O = 0.942 T – 0.673 K – 0.70 OK and for Chillies, FN = 8.29 T – 0.32 SN -40; FP = 7.13 T – 5.24 SP – 20 and FK_2O = 5.86 T – 0.15 SK – 40). where FN, FP_2O_5 and FK_2O are the fertilizers of N, P_2O_5 and K_2O in kgha$^{-1,}$ respectively. T is the targeted yield in tha^{-1}.SN is the soil available nitrogen (Alkaline $KMnO_4$-N), SP is the soil available phosphorus (Olsen P) and SK is the soil available potassium (NH_4OAc-K), which are expressed in Kgha^{-1}. ON is organic nitrogen, OP is organic phosphorus, and OK is organic potassium, which are the quantities of nitrogen, phosphorus and potassium supplied through FYM in Kgha^{-1}. The recommended doses of organic manures (Cassava: 25 t FYM ha^{-1} and Chillies: 25 t FYM ha^{-1}**)** and bioinoculants (Azospirillum @2 kgha^{-1} and Phosphobacteria @ 2 kgha^{-1}**)** were applied to the intercrops.

Cassava

Details about the cultivation practices adopted for Cassava are as follows. The field was ploughed well 4 – 5 times to obtain a fine tilth up to a soil depth of 30 cm. Ridges and furrows were formed at 90 x 90 cm. Healthy mosaic-free planting materials were selected, and the setts were cut up to a length of 15 cm with 8 to 10 nodes from the middle portion of the stem. The setts were dipped in carbendazim @1 g in a liter of water for 15 minutes before planting to prevent tuber rot. The setts were planted on the sides of the ridges, pointing upwards at a spacing of 90 x 90 cm. Farmyard manure @ 25 t/ha was applied and was incorporated at the time of planting. NPK fertilizers were applied as per the treatment schedule, and the recommended dose was @ 90:90:240 kg/ha. The fertilizers were applied at 45:90:120 kg/ha as basal, and 45:0:120 kg N and K/ha at 90 DAP during earthing up. Zinc sulphate at 25 kg/ha, 20 kg/ha of S as gypsum, and 10 kg/ha of borax were applied basally as soil application. After cultivation practices, including gap filling, weeding, plant protection measures and other cultural practices, were performed as per the recommendations of Crop production Techniques of Horticultural Crops, 2013 of Tamil Nadu Agricultural University. The gaps were filled within 20 DAP. First, weeding was carried out at 20 DAP. Subsequent weedings were carried out once in every month up to 5 months, depending on the weed intensity. Five plants from each plot were tagged and utilized for recording biometric observations of growth attributes and yield attributes at appropriate stages using standard operating procedures. The tuber yield of Cassava was observed when the crop reached the harvest stage,the tubers were pulled out, and the weight of the tuber was calculated and expressed as tonnes/ha.

Chillies

Details about the cultivation practices adopted for chillies are as follows. The field was prepared thoroughly with the addition of FYM @ 25 t/ha. Ridges

Table 1. Initial characteristics of the soil

Parameter	Values
Physical properties	
Soil textural analysis	
Sand (%)	73.03
Silt (%)	21.22
Clay (%)	3.17
Textural class	Sandy loam
Bulk density (g/cm^3)	1.42
Particle density (g/cm^3)	1.79
Porosity (%)	20.76
Water holding capacity (%)	20.88
Chemical properties	
Soil reaction (pH) (Jackson (1973)	7.50
Electrical conductivity (dS m^{-1}) (Jackson (1973)	0.38
Organic carbon (gkg^{-1}) (Walkley and Black (1934)	2.85
Available nitrogen (kg ha^{-1}) (Subbiah and Asija (1956)	156
Available phosphorus (kg ha^{-1}) (Olsen *et al.* (1954)	47
Available potassium (kg ha^{-1}) (Stanford and English (1949)	312

and furrows were formed at a spacing of 60 cm. Azospirillum and Phosphobacteria @ 2 kg/ha were applied by mixing with FYM. The furrows were irrigated, and the seedlings were transplanted at 40-45 days with a ball of earth on the ridges at a spacing of 60 x 45 cm. Weed control was performed by application of pendimethalin @ 1.0 kg a.i./ha as a pre-emergence herbicide followed by hand weeding once at 30 DAP. Irrigation was taken up at weekly intervals. NPK was applied at 30:60:90 kg/ha basally. Potassium was applied as K_2SO_4, which will increase the quality of chilli. Topdressing of 30 kg/ha of N was performed in three equal splits, i.e., at 30, 60 and 90 DAP Triocantanol at 1.25 ml/l was applied at 20, 40, 60 and 80 DAP. NAA was sprayed at 10 ppm (10 mg/l water) at 60 and 90 DAP to increase fruit set. Zinc sulphate at 0.5 % thrice at 10-day intervals from 40 DAP and Mn at 1 % at 60 DAP were sprayed as foliar sprays. Five plants from each plot were tagged and utilized for recording biometric observations of growth attributes and yield attributes at appropriate stages using standard operating procedures. The dry weight of the chilies fruit was taken, and the yield of the chillies was also recorded and expressed as tonnes/ha.The harvesting process was followed as per the Crop production Techniques of Horticultural crops, 2013 of Tamil Nadu Agricultural University.

One composite soil sample for each replication was taken from the cultivated soil layer combining 12 samples evenly distributed over the entire treatment plot. The samples were analysed in the soil analytical laboratory of the Forest College and Research Institute (FC&RI), Mettupalayam, Tamil Nadu Agricultural University. The initial soil characteristics of the experimental site showed that the soils are Alfisols with sandy loam texture, red coloured, noncalcareous and classified taxonomically as *Typic haplustalf* as per USDA. The soil was neutral in reaction with low organic carbon and available nitrogen and high in available phosphorus and potassium (Table 1). The properties showed that there was no considerable variation among the physicochemical properties among the soils at the time of planting since the comparative study was conducted in the same field. This is in accordance with the general hypothesis and earlier results reported by many researchers for alfisols and vertisols and various crops, such as cotton, vegetables and sugarcane. (Jayakumar *et al.*, 2014, 2015; Surendran and Vani, 2013; Surendran *et al.*, 2016 a,b). The average values of the meteorological parameters observed, *viz.,* rainfall, maximum and minimum temperature, and relative humidity, during the experimental period are shown in Fig. 1.

Dalbergia sissoo

The intercrops of Cassava and Chillies were raised in the field where the tree crop *Dalbergia sissoo* had been already established at a spacing of 4 m x 4 m. The growth attributes *viz.,* plant height and basal diameter of *D. sissoo* trees raised in the Cassava and Chillies intercrop field were observed at 9 months after planting (MAP).Tree height and basal diameter are important factors in surveys, the production and management of forest resources and research on forest ecosystems. These two parameters are used to calculate the tree volume and to estimate the biomass and carbon stock (Daniel and Jeffery (2009). In the present investigation, the tree height was calibrated using a direct measurement method by using a ladder or labeled pole or dropping the tape from the top (Goodwind,2004).

Post-harvest analysis of soil

The post-harvest soil samples were analysed for available nutrients, *i.e.,* N, by the alkaline $KMnO_4$ method, as outlined by Subbiah and Asija (1956), P by the olsen method of Olsen *et al* (1954) and NH_4OAc – K as outlined by Stanford and English (1949). The physico-chemical properties,*viz.,*pH and electrical conductivity, were analysed by potentiometry and conductometry (Jackson,1973), and organic carbon was analysed using the chromic acid wet digestion method (Walkley and Black, 1934).

Statistical analysis

The data collected were statistically analysed using the AGRES and SPSS software packages (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

The results of the study conducted by growing horticulture-based intercrops, *viz.,* Cassava and Chillies, along with *D. ssissoo,* for assessing the compatibility of intercrops with the tree crop in combination with nutrient management systems showed statistically significant ($p \leq 0.05$) results. The maximum temperature was recorded in the month of April and the minimum in the

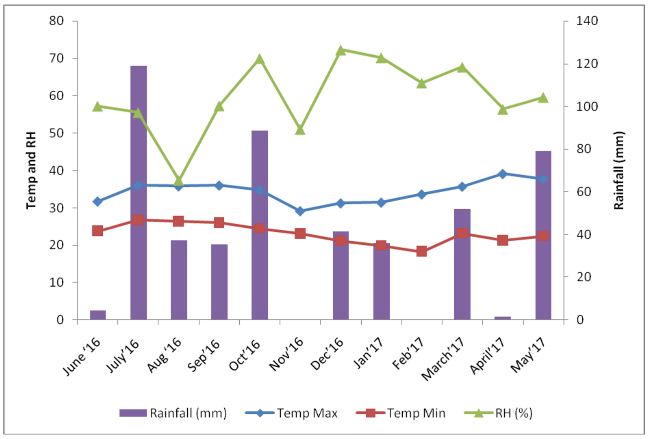

Fig. 1. *Meteorological parameters observed during the experiment period*

month of November. The total rainfall received during the experimental period was 490 mm (Fig.1).

Growth attributes

Growth attributes were significantly influenced ($p \leq 0.05$) by the treatment. The maximum tree height (297 cm) at 9 MAP of *D. sissoo* was recorded in treatment S_5 (STCR-IPNS recommendation), where Cassava was raised as the intercrop (Table 2; Fig. 2). Similarly, in the Chillies, the maximum tree height of *D. sissoo at* 9 MAP was recorded in the same treatment S_5 (STCR-IPNS recommendation). Basal diameter also showed similar results, and the maximum basal diameter at 9 MAP (37.40; 36.30 mm) was recorded in treatment S_5 (STCR-IPNS recommendation) in both Cassava and chillies. The possible reason for improved growth attributes is that the nutrient management system adopted for the intercrops might have influenced the growth of the tree crop, and similar findings were reported in *Dalbergia sissoo* by Huda *et al.* (2007), in which phosphorus and potassium applied along with cow dung increased the collar diameter of the tree crop.

The interaction effect of both the main and subplot treatments showed that in Cassava and Chilies, the treatment received fertilizer based on STCR-IPNS (M_1S_5 and M_2S_5), *Dalbergia sissoo* recorded the maximum plant height of 297 cm and 289 cm, respectively (Table 2). The percent increase in plant height over the control was 98.0 and 100.0 with respect to Cassava and Chillies, respectively. The basal diameter of *Dalbergia sissoo* in the same treatment that received fertilizer based on Soil Test Crop Response studies - Integrated Plant Nutrient Supply System in Cassava (M_1S_5) and Chillies (M_2S_5) registered maxima of 37.40 mm and 36.40 mm, respectively. The percentage increase over the control based on basal diameter was 65 and 69 in Cassava and Chillies, respectively. With regard to plant height and basal diameter, both intercrops *,viz.,* Chillies and Cassava, had no significant ($p \leq 0.05$) interaction effect.

Yield of the intercrops

The intercrops grown along with *D. sissoo* showed the highest mean yield of 17.8 t ha^{-1} and 1.60 tha^{-1} in Cassava and Chillies, respectively, in the treatment that received the fertilizer based on Soil Test Crop Response studies - Integrated Plant Nutrient Supply System recommendations (S_5). This was followed by the treatment that received 150 percent Recommended Dose of Fertilizer (S_4) (16.0 t ha^{-}1 and 1.45 t ha^{-}1, respectively) (Table 3). Statistically Significant ($p \leq 0.05$) higher yields were obtained in both Cassava and Chilies in the treatment that received the fertilizer based on Soil Test Crop Response studies - Integrated Plant Nutrient Supply System recommendations (S_5). However, in the Chillies, the highest yield was recorded in the treatment that received the fertilizer based on Soil Test Crop Response studies - Integrated Plant Nutrient Supply System (S_5), which was comparable with the treatments that received 125 percent Recommended Dose of Fertilizer (S_3)and 150 percent Recommended Dose of Fertilizer (S_4). This might be due to the application of recommended fertilizers along with the organic manures and bioinoculants that could have supplied the nutrients continuously and thereby would have led to the growth of the tree as well as the intercrop yield. The complementary effect of biofertilizers, organics and inorganics on the physical, chemical and biological properties of the soil might also have increased the tuber yield and fruit yield of Cassava and Chillies, respectively. Similar results were reported by Jaisankar *et al.* (2014), who found that the INM treatments supplied *Dalbergia sissoo* with available forms of nutrients. Tayade *et al*.(2019) also reported similar results of an increase in yield due to the combined application of poultry manure and inorganic fertilizers through STCR-IPNS-based fertilizer application in sugarcane. Similar findings were also reported by Suganya and Manickam (2016) and Byju (2012) in Cassava and Dobermann and White (1999) in Nutrient Use Efficiency in irrigated and rainfed lowland rice system.

The interaction effects of the main plots, M_1(cassava) and M_2(Chillies), and the subplots (nutrient management practices) (S_1 to S_5)treatments revealed that the yields obtained from Cassava (M_1) and Chillies (M_2) were significantly($p \leq 0.05$) higher in the treatment that received the fertilizer based on Soil Test Crop Response studies - Integrated Plant Nutrient Supply System recommendation (M_1S_5 and M_2S_5), followed by the yields obtained in both Cassava and chilies in the treatment that received 150 percent of the Recommended Dose of Fertilizer (M_1S_4 and M_2S_4). The percentage of increase in yield over the control in the case of Cassava was 117 %, whereas the percentage of increase in

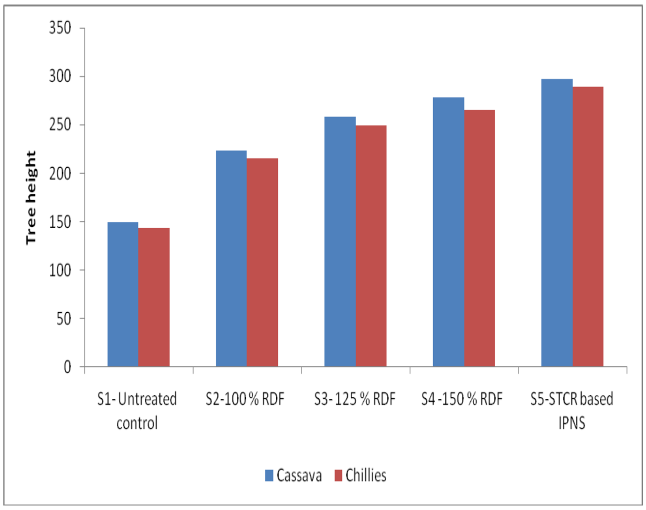

Fig. 2. *Tree height of D. Sissoo as influenced by different treatments*

Table 2. Tree height and basal diameter of *Dalbergia sissoo* in Cassava and Chillies intercropped fields at 9 MAP

Treatment	Tree height		Basal diameter	
	M_1 Height of *Dalbergia sissoo* raised in cassava field (cm)	M_2 Height of *Dalbergia sissoo* raised in chillies field (cm)	M_1 Basal diameter of *Dalbergia sissoo* raised in cassava field (mm)	M_2 Basal diameter of *Dalbergia sissoo* raised in chillies field (mm)
S_1- Untreated control	150	144	22.65	21.50
S_2-100 % RDF	223	215	27.88	25.45
S_3- 125 % RDF	258	249	31.50	30.10
S_4 -150 % RDF	278	265	34.50	33.20
S_5-STCR based IPNS	297	289	37.40	36.30
Mean	241	232	30.79	29.31
	S.Ed.	(CD = 0.05)	S.Ed.	(CD = 0.05)
Main plots (M)	NS	NS	0.04	0.13
Sub plots (S)	17.75	37.64	0.80	1.66
M at S	24.67	61.54	1.01	2.10
S at M	25.11	53.24	NS	NS

yield over the control with reference to chilies was 48 %. Therefore, the interaction effect was higher in the case of Cassava than in chilies.

Post-harvest soil analysis

The results of the analysis of the post-harvest soil samples (Table 4) showed that the pH of the samples collected from both the Cassava and Chillies fields showed that the soils were neutral(pH – Cassava-7.01 and Chillies - 7.09). The electrical conductivity values showed that the soils were nonsaline (EC – Cassava - 0.23 and Chillies - 0.39 dSm^{-1}). With respect to the initial soil properties, there was little variation in pH and EC after the experiment. The data on post-harvest soil fertility status indicated a slight build-up of available N, P and K, and the organic carbon content also increased slightly in both Cassava and Chillies over the initial soil. Improved P availability in the soil raised in the Chillies (initial - 47 $kgha^{-1}$; post-harvest–56 $kgha^{-1}$) could be attributed to reduced P sorption and the reason for the P released from the decomposition of FYM (Cong and Mercks, 2005; Laroche *et al*., 2019).

The build-up of available nitrogen (Initial -156 $kgha^{-1}$; Post-harvest-164.6 $kgha^{-1}$) and increase in OC (from 2.85 gkg^{-1} to 4.85 gkg^{-1}) noticed in the Chillies field might be attributed to the production of humic acid and humic substances from organic sources, which might have enhanced the soil physical condition; fulvic acid released from organic sources is also a good source of energy for soil microbes, which could have enhanced N mineralization and mobilization (Sarimong *et al*.2017). In the Cassava field, the available nitrogen content was sustained when compared to the initial soil, while the OC content increased (i.e.) from 2.85 gkg^{-1} to 3.45 $g\ kg^{-1}$.

Conclusion

The present investigation was taken up with *Dalbergia sissoo* as the main crop and two horticulture crops *viz.,* Cassava (*Manihot esculenta)* and Chillies (*Capsicum annum)* as intercrops to assess the benefits of intercropping in agroforestry systems and its effect on the nutrient management techniques for enhancing crop productivity and its effect on soil health. Assessment of compatibility of intercrops in *D. sissoo*-based horti silvicultural system crops *viz.,* Cassava (*M. esculenta)* and Chillies (*C.annum)* as intercrops showed that applying

Table 3. Effect of treatments on yield of intercrops, Cassava and Chillies

Treatment	M_1 Tuber yield of Cassava (t/ha)	M_2 Dry pod yield of chillies (t/ha)
S_1- Untreated control	8.2	1.12
S_2-100 % RDF	12.4	1.25
S_3- 125 % RDF	14.5	1.36
S_4 -150 % RDF	16.0	1.45
S_5-STCR based IPNS	17.8	1.60
Mean	13.8	1.38
	S.Ed.	(CD = 0.05)
Main plots (M)	0.1	0.18
Sub plots (S)	0.1	0.30
M at S	0.2	0.41
S at M	0.2	0.42

fertilizer based on the STCR-IPNS module of the nutrient management practice is the best way to enhance crop productivity. The horti silvicultural system of growing *D. sissoo* and intercrops such as Cassava and Chillies has been an economically feasible and physiologically viable model. The fertilizer applied to the intercrops also contributed to the nutrient requirement of the tree crop, thereby reducing the farmer's cost of cultivation for raising the tree crop and improving the profitability from the intercrops.

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Conflict of interest
The authors declare that they have no conflict of interest.

REFERENCES

1. Bai, W., Sun. Z., Zheng. J., Du. G., Feng. L. Cai. Q., Yang. N., Feng. C., Zhang. Z., Evers. B.J., Vander Werf. W. & Zheng.L. (2016). Mixing trees and crops increases land and water use efficiencies in a semiarid area. *Agricultural Water Management*, 178, 281–290.
2. Basavaraja, P.K.H., Mohamed Saqueebulla, G.V. Gangamrutha, Prabhudeva, D.S. & Deva P.2019 Journal of Pharmacognosy and *Phytochemistry,*8(3),3870-3873
3. Branca. G., L. Lipper., N. McCarthy & Jolejole M.C. (2013) Food security, climate change, and sustainable land management. A review. *Agronomy for Sustainable development,* 33, 635 650
4. Byju, G., Nedunchezhiyan, M., Ravindran, C.S., Santhosh Mithra, V.S., Ravi, V. & Naskar S.K. (2012). Modelling the response of Cassava to fertilizers: A site specific Nutrient Management approach for greater tuberous root yield. *Communications in soil science and plant analysis*, 43, 1149 – 1162.
5. Chaubey, A.K., Parganiha, O.P. & Parcya P.M. (2015). Effect of STCR technology for targeted yield in Rice. *Plant Archives.* 15(1),267-269.
6. Cong.P.T. and R.Merckx.2005. Improving phosphorus availability in two upland soils of Vietnam using *Tihonia diversifolia,* Plant and Soil.269:11-23.
7. Daniel, L., & Jeffery.G. (2009). A height-diameter curve for longleaf pine plantations in the gulf coastal plain, *Southern Journal of Applied forestry*, 33 (4), 164 – 170.
8. Dey. P., & Srivastava.S. (2013). Site specific Nutrient management with STCR approach in Kundu *et al*. (Eds.): IISS contribution in Frontier areas of Soil Research Indian Institute of Soil Science, Bhopal. 259-270.
9. Dobermann, A., & White P.F. (1999). Strategies for nutrient management in irrigated and rainfed lowland rice system. *Nutrient cycling in Agroecosystems* 46, 1 – 10.
10. Garrity, D. F. & F.Agus.(2000).Natural Resource Management on watershed scale. Agroforestry contribution. CRC Press, London, New York, Washigton.P.230
11. Gomez, K. A. & Gomez, A. A. (1984). *Statistical procedures for agricultural research*. John Wiley & Sons.
12. Goodwind, A.N. (2004). Measuring tall trees height from the ground. *Tasforests*, 15, 85– 97.
13. Huda, S.M.S., Sujauddin, M. Shafinat, S. & Uddin, M. S. (2007).Effect of Phosphorus and Potassium addition on ground and nodulation of *Dalbergia sissoo* in the nursery. *Journal of Forestry Research*,18, 279-282
14. Jackson, M.L. (1973) Soil chemical analysis, Prentice Hall of India Pvt. Ltd., New Delhi.
15. Jaisankar, I. Revathi, R., Umarani, R., Sivakumar, K. and HariPrasath, C.N. (2014) Effect of Integrated Nutrient Management Practices on growth and ecophysiological characters of *Dalbergia sissoo* Roxb. Clones. *Journal of Andaman Science Association* 19(1),23-29.
16. Jayakumar, M., Surendran, U. & Manickasundaram, P., (2014). Drip fertigation effectson yield: nutrient uptake and soil fertility of Bt Cotton in semi arid tropics. *International Journal of Plant Production*, 8, 375–390.
17. Jayakumar, M., Surendran, U. & Manickasundaram, P. (2015). Drip fertigation programon growth, crop productivity, water, and fertilizer-Use efficiency of bt cotton insemiarid tropical region of India. *Communications in Soil Science and Plant Analysis*, 46 (3), 293–304.
18. Jezeer, R.E. Verwej, P.A. Boot, R.G.A. Junginger M. & M. J. Santoz (2019) Influence of livelihood assets, experienced shocks and perceived risks on smallholder coffee farming practices in Peru. *J. of Env. Management,* 242, 496 - 506
19. Jose, S.(2011). Managing native and nonnative plant species in Agroforestry, *Agroforestry systems* 83, 101 – 105.
20. Laroche, G., Domon, G., Gélinas, N. (2019) Integrating agroforestry intercropping systems in contrasted agricultural landscapes: a SWOT-AHP analysis of stakeholders' perceptions. *Agroforestry Systems*, 93, 947–959 https://doi.org/10.1007/s10457-018-0191-0
21. Meylan, L., C. Gury., C. Allinne, J. Ortiz, L. Jackson & B.Rapidel.(2017) Evaluating the effect of shade trees on provision of ecosystem services in intensively managed coffee plantations. *Agric. Ecosyst. Environ*. 245: 32 - 42
22. Munz, S, Graeff-Honninger, S. Lizaso, J.L. Chen, Q. & Claupein, W. (2014). Modelling light availability for a subordinate crop within a strip intercropping system. *Field Crops Research,* 155, 77-89.
23. Nair, P.K.R., Kumar, B.M. & Nair, V.D. (2009).Agroforestry as a strategy for Carbon sequestration. *Journal of Soil Science and Plant Nutrition*, 172(1), 10 – 23.
24. Nesper, M., Kueffer, C., Krishnan, S., Kushalappa, C.G., Ghazoul, J., (2017). Shade tree diversity enhances coffee production and quality in agroforestry systems in the Western Ghats. *Agric. Ecosyst. Environ.* 247, 172–181.
25. Olsen, S.R., Cole C.V., Wattanabe, F.S. & Dean. L. A, (1954). Estimation of available phosphorus by extraction with $NaHCO_3$ Circ. US. Dept. Agri. 939 p.
26. Ramamoorthi, B.,Narasimhan. R. L. & Dinesh. R. S. (1967). Fertilizer application for Sonora 64 for specific yield targets. *Indian Farming,* 17,43-45.
27. Ram Newaj, Dhyani, S.K., Chavan, S.B., Rizvi, R.H., Rajendra Prasad, Ajit, BadreAlam & Handa, A.K. (2014). Methodologies for assessing biomass, carbon stock and C -sequestration in agroforestry systems. National Research

Centre for Agroforestry.Jhansi.P.45.

28. Sarimong, R.T., Shukla, A.K., Gill. M.S., Paterno, E. S. & Cruz, P.C.S. (2017). Effect of organic amendment and microbial inoculants on nitrogen, phosphorus and potassium use efficiency of sugarcane under acid type haplusdand. *Journal of the International Society of Asian Agricultural Science, .*23(2), 114-124
29. Schroth. G. & M.S. da Mota (2013). Agroforestry: Complex multi strata agriculture. Encyclopedia of Agriculture and Food system 2nd Edn. Elsivier Publication Eds. N.vanAlfen.
30. Singh, V. K., Shukla., Gill, M.S., Sharma, S.K. & Tiwari, K.N. (2008). Improving sugarcane productivity through balanced nutrition with potassium, sulphur and magnesium. *Better crops-India* 24,12-14.
31. Sivakumar. K., Ramah. K. & Krishnakumar N., (2019).Potential of agroforestry for soil reclamation and soil rehabilitation. In Multifunctional Agroforestry {Ecosystem services} – Eds. K.T. Parthiban., Ramah. K. and G. Rajeshwar Rao. Jaya Publishing House, New Delhi. Pp.631 – 656.
32. Stanford. S & English, L. (1949). Use of flame photometer in rapid soil tests of potassium and calcium. *Agronomy Journal*,41, 446-447
33. Subbiah, B.V. & Asija, G. L., (1956). A rapid procedure for the estimation of available nitrogen in soil. *Current Science*, 25, 258 – 260.
34. Suganya. S. & Manickam.S. (2016). Soil test crop response based integrated plant nutrient supply for Cassava in a *Typic Rhodustalf* of Tamil Nadu for sustainable Livelihood. *Journal of Root Crops*, 42 (2), 39-43.
35. Surendran, U. & Vani, D., (2013). Influence of arbuscular mycorrhizal fungi insugarcane productivity under semiarid tropical agroecosystem in India. *International Journal of Plant Production,* 7 (2), 269–278.
36. Surendran, U., Ramesh, V., Jayakumar, M., Marimuthu, S. & Sridevi, G., (2016a). Improved sugarcane productivity with tillage and trash management practices in semi arid tropical agroecosystem in India. *Soil and Tillage Research,* 158, 10–21, http://dx.doi.org/10.1016/j.still.2015.10.009.
37. Surendran, U., Ramasubramoniam, S., Raja, P., Kumar, V. & Murugappan, V., (2016b).Budgeting of major nutrients and the mitigation options for nutrient mining in semi arid tropical agroecosystem of Tamil Nadu, India using NUTMON model. *Environment and Monitoring and Assessment*, 188 (4), 1–17.
38. Tayade, A. S., Bhaskaran. A & Anusha, S. (2019). IPNS-STCR based Nutrient management modules for enhancing soil health, fertilizer-use efficiency, productivity and profitability of tropical Indian sugarcane plant-ratoon agroecosystem. *Sugar Technology,* 22(2),1-10
39. Udawatta. P. Ranjith, Robert J. Kremerc, Brandon W. Adamsona & Stephen H. Anderson (2008). Variations in soil aggregate stability and enzyme activities in a temperate agroforestry practice. *Applied Soil Ecology*, 39, 153–160
40. Walkley A. J. & Black, I.A. (1934) Estimation of soil organic carbon by the chromic acid titration method. *Soil Science*, 37, 29-38.