International Journal of Bio-resource and Stress Management 2014, 5(3):350-355
DOI:10.5958/0976-4038.2014.00579.X
Full Research Article

# Wheat (*Triticum aestivum* L.) Yield and Soil Properties as Influenced by Different Agri-silviculture Systems of Terai Region, Northern India

**S. Sarvade[1*], H. S. Mishra[2], Rajesh Kaushal[3], Sumit Chaturvedi[4] and Salil Tewari[5]**

[1]Dept. of Silviculture and Agroforestry, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan, HP (173 230), India
[2-5]G. B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand (263 145), India

**Article History**

Manuscript No. AR798
Received in 29th July, 2014
Received in revised form 22nd July, 2014
Accepted in final form 29th July, 2014

**Correspondence to**

*E-mail: samforester@rediffmail.com

***Keywords***

Agri-silvicultural systems, wheat, yield, soil physico-chemical properties

**Abstract**

Field experiment was conducted during *rabi* season of 2008-2009 on an established plantation at Agroforestry Research Centre, Haldi, G. B. Pant University of Agriculture and Technology, Pantnagar to evaluate the effect of tree species and their spacing on yield of intercrop wheat (variety PBW-502) and soil properties. The experiment was laid out in split-plot design with 3 replications. The highest grain yield (36.0 q $ha^{-1}$) was obtained under open farming system (control). The reduction in grain yield was in the range of 16 to 62% under agroforestry systems as compared to control. Poplar based agri-silvicultural system performed better as compared to other systems. Highest wheat yield was recorded in 3.0×2.5 $m^2$ spacing under Poplar, Melia, and *Leucaena* based agri-silvicultural system but in the case of Eucalyptus, 3.0×2.0 $m^2$ spacing was the best. The organic carbon was highest under Poplar (1.73%) as compared to control (0.60%). The electrical conductivity was significantly lowered under Leucaena interfaces as compared to control. Whereas, soil pH was lowered under Poplar (at 3.0×2.0 $m^2$) and statistically similar with Leucaena (at 3.0×1.0 $m^2$). Bulk density was significantly decreased under Leucaena and Melia interfaces at 3.0×1.0 $m^2$ spacing. Highest available N, $P_2O_5$ and $K_2O$ content (200.42, 18.67 and 169.12 kg $ha^{-1}$, respectively) were observed in the soil under Leucaena (3.0×2.0 $m^2$).

## 1. Introduction

Wheat (*Triticum aestivum* L.) is widely intercropped cereal crop during *rabi* season (November-April) with Poplar, Eucalyptus and other fast growing tree species in northern states of India viz., Uttarakhand, Punjab, Haryana, Uttar Pradesh and Bihar, parts of central and eastern states such as Madhya Pradesh, Chhattisgarh and West Bengal. Poplar and Eucalyptus are the most successful industrial agroforestry tree species in India with extremely high productivity up to 10-30 $m^3 ha^{-1} yr^{-1}$. Intercropping with high density short rotation tree species is the best option to meet increasing food and industrial raw material requirement through sustainable utilization of natural resources (Sarvade et al., 2014). Cropping with tree species is an ancient practice and very important tool to achieve goal of National Forest Policy (1988). It has been reported as an important component of the 'evergreen revolution' movement in the country (Puri and Nair, 2004). The tree species behave differently at different planting densities. Spacing and planting layout of the tree species influence growth and yield of annual crops. Appropriate selection of tree and crop species helps to increase yield, improve soil fertility, promote land sustainability and resource use efficiency (Sharma et al., 2004; Muthuri et al., 2005; Jose, 2009; Dhyani et al., 2009; Jha et al., 2010; Antonio and Gama-Rodrigues, 2011). The resource sharing by the components may result in complementary or competitive effects depending upon the nature of the species involved in the system and climatic factors (Garrity, 2004).

In view of this, an experiment was carried out to investigate the effect of high density short rotation tree species on wheat crop.

## 2. Material and Methods

A field experiment was carried out during *rabi* season of 2008-09 at Agroforestry Research Centre, Haldi of G.B. Pant University of Agriculture and Technology, Pantnagar, District Udham Singh Nagar, Uttararakhand, India. The centre is located at $29^0$ 00'N latitude, $79^0$ 30' E longitude and

 

243.84 meters amsl elevation, which lies in the foothills of the Shivalik range of the Himalayas in the narrow strip called '*terai*'. The soils of *terai* region developed from calcareous, medium to moderately coarse textured materials under predominant influence of tall vegetation and moderate to well drain conditions. The site had humid sub-tropical climate with cold and hot dry summers.

The four tree species viz., *Populus deltoides* ($T_1$), *Eucalyptus camaeldulensis* ($T_2$), *Leucaena leucocephala* ($T_3$) and *Melia azedarach* ($T_4$), were planted at 3.0×1.0 $m^2$ ($S_1$), 3.0×1.5 $m^2$ ($S_2$), 3.0×2.0 $m^2$ ($S_3$), 3.0×2.5 $m^2$ ($S_4$) spacing during 2007. The wheat (*Triticum aestivum* L.), variety PBW-502 was raised with the recommended cultural practices during 2008-09. The experimental design was split plot and replicated thrice.

The effect of tree species and their spacing on wheat crop was estimated in terms of yield (biological, straw and grain). Grain, straw and biological yield (q $ha^{-1}$) was determined on the net plot (3.0 $m^2$) area basis. Soil samples were collected after harvesting of the wheat crop from net plots for the study of nutrient status and physico-chemical properties viz., available nitrogen, potassium and phosphorus, bulk density, organic carbon, pH and EC.

Data obtained during the course of this investigation, was analyzed by using analysis of variance (ANOVA) technique (Snedecor and Cochran, 1967) with the help of Statistical Package for the Social Sciences for windows version 16.0 (SPSS Inc.,Cary, NC, USA). The significant differences between treatment means were compared with the Tukey-Kramer HSD test ($p$=0.05) by using JMP SAS software package.

## 3. Results and Discussion

### 3.1. Crop yield

Grain, straw and biological yield of wheat was decreased significantly by fast growing short rotation tree species as compared to control (Figure 1). Maximum grain, straw and biological yield was registered from the Poplar interface, followed by Leucaena and Melia interfaces. Grain yield was significantly affected by spacing, whereas straw and biological yield were nonsignificant. The wider tree spacing ($S_4$) recorded highest grain, straw and biological yield, which was closely followed by $S_3$, $S_2$ and $S_1$.

The effect of tree species and their planting spacing interactions were non-significant (Table 1) for grain, straw and biological yield ($p$>0.05). Whereas, highest grain (32.92 q $ha^{-1}$), straw (47.74 q $ha^{-1}$) and biological (80.66 q $ha^{-1}$) yield was recorded from $T_1 \times S_4$ treatment combination.

Light, moisture and nutrients are the most important limiting factors which influence the overall growth and yield of agroforestry systems. Significant yield reduction by tree species could be due to their shading effect and belowground competition for resources. Allelopathic effect is one of the

Table 1: Wheat yield and soil nutrient status under fast growing tree species planted at different spacings

| Tree spp. | Spacing | Yield (q $ha^{-1}$) | | | Soil nutrients (kg $ha^{-1}$) | | |
|---|---|---|---|---|---|---|---|
| | | Grain | Straw | Biological | Available N | Available $P_2O_5$ | Available $K_2O$ |
| $T_1$ | $S_1$ | 21.36±1.03$^{ab}$ | 37.15±4.01$^{a}$ | 58.51±6.45$^{a}$ | 182.46±7.49$^{abc}$ | 15.99±5.24$^{abc}$ | 158.76±10.22$^{a}$ |
| | $S_2$ | 24.68±1.04$^{ab}$ | 37.00±3.17$^{a}$ | 61.68±5.18$^{a}$ | 180.69±18.88$^{ab}$ | 12.28±1.20$^{abc}$ | 155.01±11.94$^{a}$ |
| | $S_3$ | 30.02±2.50$^{ab}$ | 45.03±3.75$^{a}$ | 75.05±6.26$^{a}$ | 190.52±9.45$^{abc}$ | 17.25±1.35$^{ab}$ | 162.94±15.04$^{a}$ |
| | $S_4$ | 32.92±3.05$^{a}$ | 47.74±4.42$^{a}$ | 80.66±7.47$^{a}$ | 175.66±18.20$^{abc}$ | 11.42±2.74$^{bc}$ | 153.60±15.49$^{a}$ |
| $T_2$ | $S_1$ | 20.00±4.61$^{b}$ | 34.89±8.02$^{a}$ | 54.89±12.63$^{a}$ | 157.68±16.29$^{abc}$ | 10.56±2.93$^{bc}$ | 153.92±13.31$^{a}$ |
| | $S_2$ | 20.87±3.60$^{ab}$ | 33.60±5.80$^{a}$ | 53.60±9.40$^{a}$ | 159.39±1.42$^{bc}$ | 11.86±2.16$^{abc}$ | 148.06±11.48$^{a}$ |
| | $S_3$ | 23.00±2.10$^{ab}$ | 35.65±3.25$^{a}$ | 58.65±5.34$^{a}$ | 168.62±7.45$^{bc}$ | 11.97±1.67$^{abc}$ | 156.61±14.87$^{a}$ |
| | $S_4$ | 19.66±3.70$^{b}$ | 29.29±5.52$^{a}$ | 48.95±9.22$^{a}$ | 161.42±11.89$^{bc}$ | 13.83±1.94$^{abc}$ | 139.01±3.39$^{a}$ |
| $T_3$ | $S_1$ | 23.16±4.66$^{ab}$ | 33.34±9.28$^{a}$ | 56.50±12.31$^{a}$ | 177.76±2.10$^{a}$ | 14.26±1.89$^{abc}$ | 153.55±14.72$^{a}$ |
| | $S_2$ | 26.16±3.64$^{ab}$ | 30.28±7.16$^{a}$ | 56.44±9.39$^{a}$ | 179.18±14.19$^{abc}$ | 14.60±2.98$^{abc}$ | 163.71±15.60$^{a}$ |
| | $S_3$ | 24.50±5.54$^{ab}$ | 41.17±6.16$^{a}$ | 65.67±13.86$^{a}$ | 200.42±9.40$^{abc}$ | 18.67±1.28$^{a}$ | 169.12±6.05$^{a}$ |
| | $S_4$ | 27.83±6.01$^{ab}$ | 40.60±9.35$^{a}$ | 68.43±14.71$^{a}$ | 180.49±5.91$^{abc}$ | 14.65±1.93$^{abc}$ | 148.61±6.92$^{a}$ |
| $T_4$ | $S_1$ | 20.33±5.66$^{ab}$ | 37.99±7.64$^{a}$ | 58.32±14.94$^{a}$ | 164.88±6.86$^{abc}$ | 13.67±1.00$^{abc}$ | 153.04±16.18$^{a}$ |
| | $S_2$ | 19.16±4.53$^{b}$ | 41.33±5.75$^{a}$ | 60.49±11.69$^{a}$ | 154.97±8.34$^{bc}$ | 12.85±0.96$^{abc}$ | 161.42±2.54$^{a}$ |
| | $S_3$ | 27.44±4.10$^{ab}$ | 36.75±8.32$^{a}$ | 64.19±10.26$^{a}$ | 168.26±9.74$^{c}$ | 16.14±1.24$^{abc}$ | 163.34±3.65$^{a}$ |
| | $S_4$ | 28.00±6.45$^{ab}$ | 40.35±8.71$^{a}$ | 68.35±15.80$^{a}$ | 163.22±8.59$^{bc}$ | 9.46±2.01$^{c}$ | 147.44±8.80$^{a}$ |
| Control | | 36.00±4.25 | 47.88±6.41 | 83.88±7.85 | 156.54±6.24 | 08.65±1.54 | 145.34±5.23 |
| P values | | 0.2656 | 0.3412 | 0.3268 | 0.6141 | 0.0193 | 0.2583 |

important causes of crop yield reduction in agroforestry systems (Kumar et al., 2008; Prasad et al., 2010; Uniyal and Chhetri, 2010). The higher wheat yield under Poplar compared to other tree interfaces may be due to their leaf shedding habit before wheat sowing in winter season and tree-crop complementary effects for resource allocation (Prakash et al., 2011; Chauhan et al., 2012). Wider tree spacing reduces the tree-crop competition and increases crop yield. Prasad et al. (2010); Singh and Pandey (2011) found that the tree density and rotation length of tree species could affect crop yield. Substantial yield advantages have been reported for Poplar-wheat system in India resulting from temporal separation of resource capture, especially light, because wheat is generally sown in autumn (November), following leaf fall in poplar, and reaches maturity prior to renewed flushing of the trees in the following spring (Chauhan et al., 2011; Sarvade et al., 2014). There are many evidences of more yield reduction with higher light interception (Rao et al., 2007). Muchiri et al. (2005) reported that the impact of trees on resource availability increases with tree size but decreases closer to the tree rows. The reduced biomass and grain yields in the agroforestry treatments relative to sole wheat demonstrate the existence of competition, as reported by Sarvade et al. (2014). The yield reduction under Leucaena was lower as compared to other species; this effect may have originated from its ability to fix atmospheric nitrogen, which may have been transferred from the soil to associated crops (Kumar et al. 2008; Sarvade et al., 2014).

### 3.2. *Soil physico-chemical properties*

Soil bulk density and electrical conductivity were significantly affected by tree species, whereas organic carbon was non-significant. The soil bulk density (1.34 Mg $m^{-3}$) was lowered under Poplar and Leucaena interfaces. Highest organic carbon (1.26%) was recorded from Poplar interfaces. The lowest electrical conductivity (0.34 $dSm^{-1}$) was recorded under Leucaena interfaces. Different tree spacing treatments affect significantly on soil bulk density organic carbon and electrical conductivity. The $S_1$ spacing recorded lower bulk density (1.32 Mg $m^{-3}$) and higher organic carbon (1.30%), whereas lower electrical conductivity (0.37 $dSm^{-1}$) recorded at $S_3$ spacing (Figure 2). Soil pH was significantly affected by tree species, whereas tree spacing was nonsignificant. Soil pH was significantly influenced by tree species and their spacing interactions (Table 2). The significantly lowest (7.1) value of soil pH was recorded under $T_3 \times S_1$ and $T_1 \times S_3$ treatment combinations whereas; it was highest (7.7) at $T_2 \times S_2$ treatment

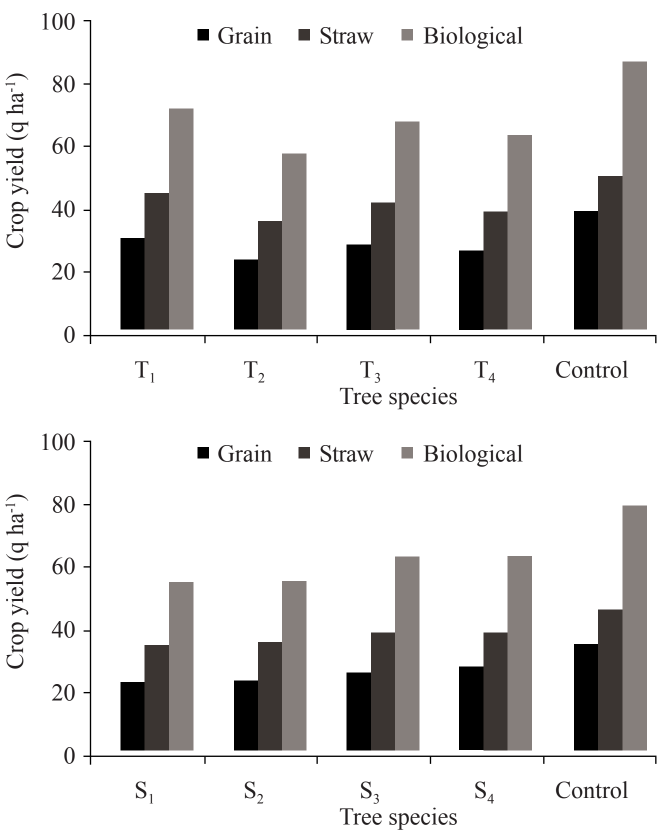


Figure 1: Effect of tree species and their spacing on yield of wheat crop

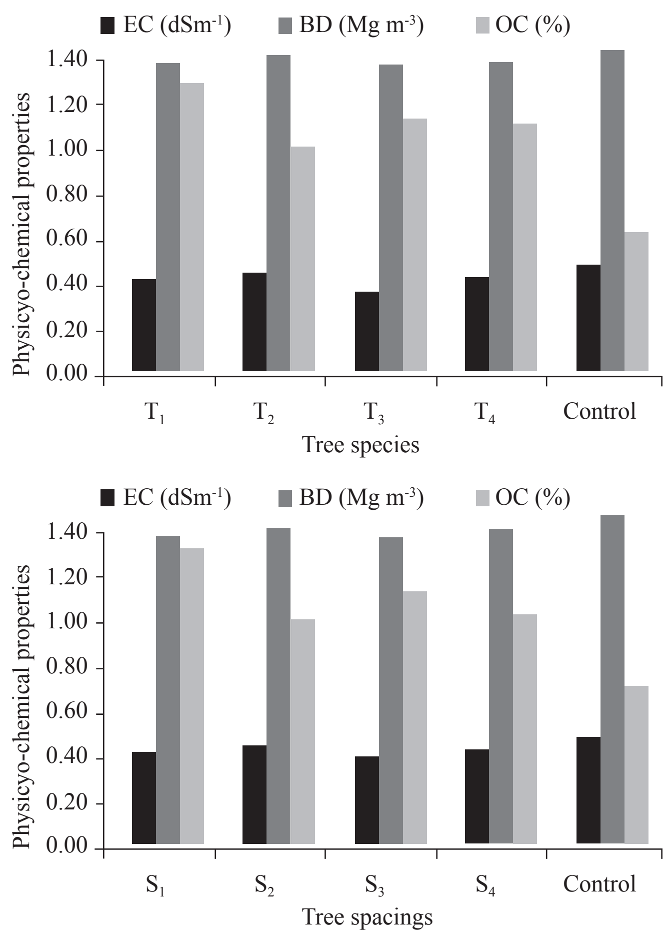


Figure 2: Effect of tree species and their spacing on soil physico-chemical properties

combination. Soil electric conductivity, bulk density and organic carbon were non-significantly affected by different fast growing short rotation tree species and their spacing interactions. The soil electrical conductivity was lower under $T_3 \times S_3$, whereas statistically *at par* with $T_3 \times S_1$, $T_3 \times S_2$, $T_1 \times S_1$ and $T_1 \times S_3$ treatment combinations. The lower bulk density (1.31 Mg $m^3$) of soil was recorded under $T_1 \times S_1$, $T_3 \times S_1$ and $T_4 \times S_1$, whereas, it was higher (1.42 Mg $m^{-3}$) under $T_2 \times S_4$ treatment combination. The higher soil organic carbon (1.73%) was recorded from $T_1 \times S_1$, whereas, it was statistically identical with $T_1 \times S_3$, $T_3 \times S_1$, $T_3 \times S_2$ and $T_4 \times S_1$ treatments (Table 2).

High organic matter content in the intercropping treatment could be ascribed to the fact that leaf fall before and during crop sowing period on the soil which incorporates in to the soil through tillage practices and their partial decomposition adds to the soil organic matter. These results are similar with the results reported by Gupta and Sharma (2009), Das and Chaturvedi (2005) and Yadav et al. (2008). The reduction of soil pH and EC under the tree cover can be attributed to accumulation and subsequent decomposition of organic matter which releases organic acids (Gupta and Sharma, 2009). Corroborative results were reported by Aguiar et al. (2010) with six month study on litter production under Poplar. Bulk density is an indication of the soil fertility as it affects the compactness, aeration, porosity, structure and root penetration. The reduction in bulk density may be due to higher accumulation of organic matter in the soil under plantation.

### 3.3. *Soil nutrient status*

Available soil N and $P_2O_5$ were significantly, whereas available $K_2O$ was nonsignificantly influenced by tree species and their spacing treatments (Figure 3 and 4). The highest available soil N (184.46 kg $ha^{-1}$), $P_2O_5$ (15.55 kg $ha^{-1}$) and $K_2O$ (158.75 kg $ha^{-1}$) were recorded under Leucaena interfaces. Tree spacing showed non-significant effect on the soil available nutrients. The $S_3$ tree spacing recorded highest available soil N (179.94 kg $ha^{-1}$), $P_2O_5$ (15.23 kg $ha^{-1}$) and $K_2O$ (158.71 kg $ha^{-1}$).

The data presented in Table 1 showed significant effect of tree species and spacing interactions on available soil $P_2O_5$ whereas, interaction effect of tree species and spacing on available soil N and $K_2O$ in soil was nonsignificant. The highest values for soil nutrients were recorded from $T_3 \times S_3$ treatment combination.

Nutrients are made available to plants in agroforestry mainly by atmospheric nitrogen fixation and mineralization of nutrients from organic forms (Muthuri et al., 2005; Fang et al., 2008; Jose, 2009; Hymavathi et al., 2010). The intercropping of trees with crops that are able to biologically fix nitrogen is common in tropical agroforestry systems. Non N-fixing trees can also enhance soil physical, chemical and biological properties by adding significant amount of organic matter and releasing

Table 2: Soil physico-chemical properties under fast growing tree species planted at different spacings

| Tree spp. | Spacing | Soil physico-chemical properties | | | |
|---|---|---|---|---|---|
| | | pH | E.C. (dS $m^{-1}$) | B.D. (mg $m^{-3}$) | O.C. (%) |
| $T_1$ | $S_1$ | 7.3±0.10[bcd] | 0.38±0.021[bcdef] | 1.31±0.020[d] | 1.73±0.48[a] |
| | $S_2$ | 7.4±0.15[abcd] | 0.41±0.020[bc] | 1.33±0.012[cd] | 1.05±0.23[b] |
| | $S_3$ | 7.1±0.15[d] | 0.36±0.021[cdef] | 1.35±0.010[bcd] | 1.22±0.34[ab] |
| | $S_4$ | 7.5±0.10[abcd] | 0.40±0.021[bcd] | 1.37±0.010[abc] | 1.04±0.11[b] |
| $T_2$ | $S_1$ | 7.6±0.15[ab] | 0.42±0.021[bc] | 1.34±0.006[bcd] | 1.04±0.07[b] |
| | $S_2$ | 7.7±0.12[a] | 0.40±0.021[bcd] | 1.39±0.027[ab] | 1.04±0.04[b] |
| | $S_3$ | 7.4±0.15[abcd] | 0.39±0.015[bcd] | 1.37±0.056[abc] | 0.97±0.08[b] |
| | $S_4$ | 7.6±0.15[abc] | 0.48±0.026[a] | 1.42±0.010[a] | 0.85±0.05[b] |
| $T_3$ | $S_1$ | 7.1±0.12[d] | 0.33±0.015[ef] | 1.31±0.010[d] | 1.19±0.10[ab] |
| | $S_2$ | 7.3±0.15[abcd] | 0.35±0.015[def] | 1.34±0.006[bcd] | 1.01±0.27[ab] |
| | $S_3$ | 7.2±0.10[cd] | 0.32±0.021[f] | 1.32±0.012[cd] | 1.32±0.20[b] |
| | $S_4$ | 7.4±0.12[abcd] | 0.38±0.020[bcde] | 1.37±0.015[abc] | 0.78±0.24[b] |
| $T_4$ | $S_1$ | 7.4±0.15[abcd] | 0.39±0.030[bcd] | 1.31±0.020[d] | 1.23±0.02[ab] |
| | $S_2$ | 7.3±0.12[abcd] | 0.41±0.021[bcd] | 1.35±0.010[bcd] | 0.97±0.17[b] |
| | $S_3$ | 7.5±0.10[abcd] | 0.40±0.025[bcd] | 1.35±0.015[bcd] | 1.11±0.13[b] |
| | $S_4$ | 7.4±0.15[abcd] | 0.43±0.010[ab] | 1.39±0.010[ab] | 1.07±0.05[b] |
| Control | | 7.7±0.10 | 0.45±0.012 | 1.40±0.027 | 0.60±0.02 |
| P value | | 0.0128 | 0.0548 | 0.5717 | 0.0511 |

Means followed by different letters are significantly different at $p$=0.05, according to Tukey-Kramer HSD test (Values are mean±SD)

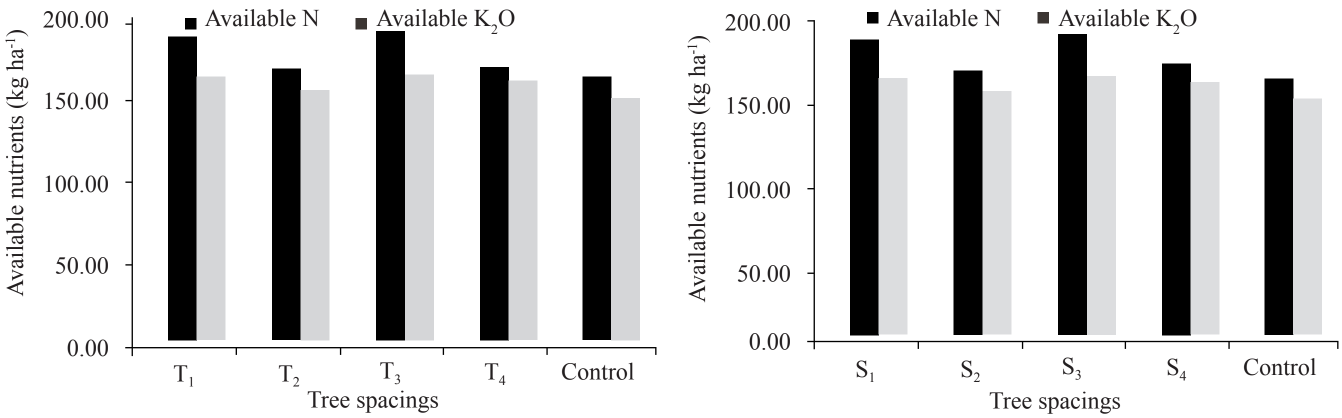


Figure 3: Effect of tree species and their spacing on available soil nutrients

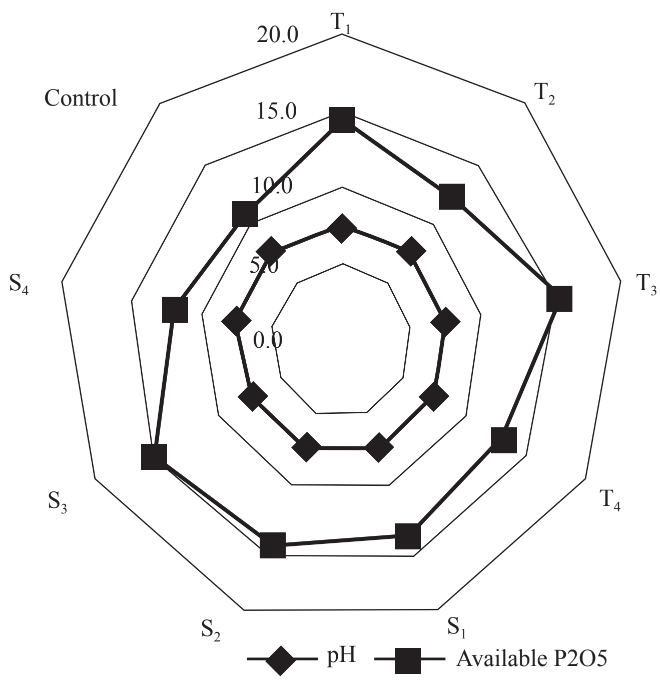


Figure 4: Effect of tree species and their spacing on soil pH and available $P_2O_5$

and recycling of nutrients in agroforestry systems (Paoli et al., 2008; Yadav et al. 2008; Antonio and Gama-Rodrigues, 2011). Leucaena, therefore, appears well suited for improving soil fertility and restoring degraded lands (Jha et al., 2010; Hymavathi et al., 2010).

## 4. Conclusion

The crop yield was higher under Poplar at 3.0×2.5 $m^2$ spacing as compared to other tree species and their spacing treatments. Poplar and Leucaena trees at 3.0×1.0 $m^2$ spacing showed a trend of improvement in soil physico-chemical properties, whereas competition for resources at closer spacing reduces the crop yield. The soil nutrient status was improved under Leucaena tree interfaces at 3.0×2.0 $m^2$ spacing.

## 5. References

Aguiar, A.C.F., Bicudo, S.J., Sobrinho, J.R.S.C., Martins, A.L.S., Coelho, K.P., Moura, E.G., 2010. Nutrient recycling and physical indicators of an alley cropping system in a sandy loam soil in the pre-Amazon region of Brazil. Nutrient Cycling in Agroecosystems 86, 189-198.

Antonio, C., Gama-Rodrigues., 2011. Soil organic matter, nutrient cycling and biological dinitrogen-fixation in agroforestry systems. Agroforestry Systems 81, 191-193.

Chauhan, S.K., Brar, M.S., Sharma, R., 2012. Performance of poplar (*Populus deltoides* bartr.) and its effect on wheat yield under agroforestry system in irrigated agro-ecosystem, India. Caspian Journal of Environmental Sciences 10(1), 53-60.

Chauhan, S.K., Gupta, N., Walia, R., Yadav, S., Chauhan, R., Mangat, P.S., 2011. Biomass and carbon sequestration potential of poplar-wheat inter-cropping system in irrigated agro-ecosystem in India. Journal of Agricultural Science and Technology A1, 575-586.

Das, D.K., Chaturvedi, O.P., 2005. Structure and function of *Populus deltoides* agroforestry system in eastern India: 1 Dry matter dynamics. Agroforestry Systems 65(3), 215-221.

Dhyani, S.K., Ajit, Handa, A.K., 2009. Agroforestry potential and scope for development across agro-climatic zones in India. Indian Journal of Forestry 32(2), 181-190.

Fang, S., Huayong, L., Baodong, X., 2008. Decomposition and nutrient release of four potential mulching materials for poplar plantations on upland sites. Agroforestry Systems 74, 27-35.

Garrity, D.P., 2004. Agroforestry and the achievement of the millennium development goals. Agroforestry Systems 61, 5-17.

Gupta, M.K., Sharma, S.D., 2009. Effect of tree plantation on soil properties, profile morphology and productivity index: poplar in Yamunanagar district of Hariyana. Annals of Forestry 17(1), 43-70.

Hymavathi, H.N., Kandhya, A.K., Patil, L.P., 2010. Beneficial effects of multiple plantations in agroforestry systems. Indian Forester 4, 465-475.

Jha, P., Mohapatra, K.P., Dubey, S.K., 2010. Impact of land use on physico-chemical and hydrological properties of ustifluvent soils in riparian zone of river Yamuna, India. Agroforestry Systems 80, 437-445.

Jose, S., 2009. Agroforestry for ecosystem services and environmental benefits: an overview. Agroforestry Systems 76, 1-10.

Kumar, M., Lakiang, J.J., Singhshi, S., 2008. Tree-crop interactions in the agroforestry systems of Mizoram. Journal of Tropical Forest Science 20(2), 91-98.

Muthuri, C.W., Ong, C.K., Black, C.R., Ngumi, V.W., Mati, B.M., 2005. Tree and crop productivity in *Grevillea*, *Alnus* and *Paulownia*-based agroforestry systems in semi-arid Kenya. Forest Ecology and Management 212, 23-39.

Paoli, G.D., Curran, L.M., Slik, J.W.F., 2008. Soil nutrients affect spatial patterns of aboveground biomass and emergent tree density in southwestern Borneo. Oecologia 155, 287-299.

Prakash, O., Dubey, R.K., Dubey, S.K., Deshwal, J.S., 2011. Evaluation of Ber (*Zizyphus mauritiana* Lamk) based agri-horti systems under various tree root management practices on reclaimed Yamuna ravines. Indian Journal of Soil Conservation 39(1), 59-62.

Prasad, J.V.N.S., Korwar, G.R., Rao, K.V., Mandal, U.K., Rao, C.A.R., Rao, G.R., Ramakrishna, Y.S., Venkateswarlu, B., Rao, S.N., Kulkarni, H.D., Rao, M.R., 2010. Tree row spacing affected agronomic and economic performance of Eucalyptus-based agroforestry in Andhra Pradesh, Southern India. Agroforestry Systems 78, 253-267.

Puri, S., Nair, P.K.R., 2004. Agroforestry research for development in India: 25 years of experiences of a national program. Agroforestry Systems 61, 437-452.

Rao, V.M., Patil, S.J., Kumar, K.S., 2007. Effect of photosynthetically active radiation on yield of groundnut in a teak based agroforestry system. Karnataka Journal of Agricultural Sciences 20(3), 605-607.

Sarvade, S., Mishra, H.S., Rajesh Kaushal, Sumit Chaturvedi, Salil Tewari and Jadhav, T.A., 2014. Performance of wheat (*Triticum aestivum* L.) crop under different spacings of trees and fertility levels. African Journal of Agricultural Research 9(9), 866-873.

Sharma, P., Rai, S.C., Sharma, R., Sharma, E., 2004. Effects of land use change on soil microbial C, N and P in a Himalyan watershed. Pedobiologia 48, 83-92.

Singh, V.S., Pandey, D.N., 2011. Multifunctional agroforestry systems in India: science-based policy options. Climate Change and CDM Cell Rajasthan State Pollution Control Board, Jaipur. 35.

Snedecor, G.W., Cochran, G.W., 1967. Statistical methods. 6$^{th}$ ed. Calcutta. IBH Publishing Company, 310.

Uniyal, A.K., Chhetri, S., 2010. An assessment of phytotoxic potential of promising agroforestry trees on germination and growth pattern of traditional field crops of Sikkim Himalaya, India. 2010. American-Eurasian Journal of Agricultural and Environmental Sciences 9(1), 70-78.

Yadav, R.S., Yadav, B.L., Chhipa, B.R., 2008. Litter dynamics and soil properties under different tree species in a semi-arid region of Rajasthan, India. Agroforestry Systems 73, 1-12.