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Influence of Perennial Fodder Tree Species on Chemical Properties of Soil Under Fodder Trees-Based Agroforestry System

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ABSTRACT

The present field investigation was conducted in Northern Transitional zone of Dharwad region at University of Agricultural Sciences, Dharwad campus, Karnataka during the period 2018-19 and 2019-20. Seven fodder tree species were planted at a spacing of 5 × 3m, viz., *Calliandra calothyrsus, Albizia lebbeck, Leucaena leucocephala, Sesbania grandiflora, Gliricidiasepium, Moringa oleifera and Bauhinia purpurea* during 2014. The experiment was laid out in Randomized Block Design (RBD) with three replications. The main objective was to study the influence of fodder tree based agroforestry system on soil chemical properties. A significant soil improvement was observed through enhancement of soil organic matter, available soil nitrogen, available phosphorus, available potassium and biological activity after two years of investigation (2018 and 2019). Soil organic carbon was in the order of T_3-*Leucaena leucocephala*+ FC (0.776 %) > T_5-*Gliricidia sepium*+ FC (0.774 %) > T_4-*Sesbania grandiflora* + FC (0.672 %) > T_7 - *Bauhinia purpurea* + FC (0.665 %) > T_2-Albizia lebbeck+ FC (0.660 %) > T_6-*Moringa oleifera* + FC (0.634 %) > T_1- *Calliandra calothyrsus*+ FC (0.614 %). The highest available nitrogen, available phosphorus and available potassium were found to have maximum in soybean as a sole crop (T_8 - Control), whereas, among agroforestry systems, Albizia lebbeck + Soybean showed highest value of soil macro nutrients before sowing and after harvesting field crops during study periods. The study showed maximum available sulphur after harvesting soybean in T_6 - *Moringa oleifera* + Soybean and T_4 - Sesbania grandiflora + Soybean. Whereas, after harvesting safflower, it was highest in T_5 - *Gliricidiasepium* + Safflower and T_6 - *Moringa oleifera* + Safflower. Available copper (ppm) in soil after harvesting soybean was highest in T_7 - Bauhinia purpurea + Soybean and it was maximum in T_6 - *Moringa oleifera* + Safflower after harvesting safflower during the study periods. Available iron after harvesting soybean was highest in *Bauhinia purpurea* + Soybean (T_7) agroforestry system and it was found highest after harvesting safflower in T_6 - *Moringa oleifera* + Safflower and T_4 - *Sesbania grandiflora* + Safflower. The highest available manganese in soil was recorded in T_7 - *Bauhinia purpurea* + Soybean and T_3 - *Leucaena leucocephala* + Soybean after harvesting soybean. After harvesting safflower, it was maximum in T_6 - *Moringa oleifera* + Safflower andT_7 - *Bauhinia purpurea* + Safflower. Available zinc (ppm) in soil after harvesting soybean attained highest in T_7 - Bauhinia purpurea + Soybean and T_6 - *Moringa oleifera* + Soybean. After harvesting of safflower, it was highest in T_7 - *Bauhinia purpurea* + Safflower. Available boron (ppm) in soil after harvesting of soybean was highest in T_3 - *Leucaena leucocephala*+ Soybean. But after harvesting of safflower, it was maximum in T_3 - *Leucaena leucocephala*+ Safflower and T_4 - *Sesbania grandiflora* + Safflower agroforestry systems.

Keywords: Chemical properties, Fodder trees, Inorganic fertilizers, Nitrogen fixation, soil organic matter

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INTRODUCTION

Agroforestry is considered as a collective name for structured arrangements of land use and traditions, in which woody perennial components are intentionally combined with crops and/or animals on the equivalent land management component. The land use systems comprising of tree, crops and pastures contribute in enhancing soil fertility and its quality by many ways. Many research outcomes reported the influence of agroforestry models to prevent soil erosion,

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sustain soil organic matter, keep up soil physical properties, supplement nitrogen fixation, enhance soil nutrient inputs, endorse efficient nutrient cycling, decrease soil toxicities, advance desirable soil faunal activity, expand soil water accessibility to crops, and the role of root systems in agroforestry (Young, 1991).

Many agroforestry systems are contributing massive application in many tropical regions and mitigating decline in agricultural productivity and natural resources. If fodder trees are integrated with inorganic fertilizers, the crop yield can be doubled or tripled in degraded lands. In zero grazing systems, fodder trees can supplement or substitute commercial feeds. Improved varieties of temperate and tropical fruits can supplement household incomes and nutrition (Bashir *et al*., 2006).

Tree components can influence both the supply and accessibility of nutrients in the soil. Trees can enhance the availability of nutrients in the course of increased release of nutrients from soil organic matter (SOM) and recycling of organic deposits. Many agroforestry trees provide nitrogen in quantities to carry moderate crop yields through nitrogen inputs by the process of biological nitrogen fixation and improvement of nitrate from deep soil layers and cycling of nitrogen from plant remains and compost. The cycling of phosphorus from organic materials is normally inadequate to fulfil phosphorus requirements of crops. Hence, sustainable crop production with agroforestry on phosphorus lacking soils will normally need external phosphorus inputs (Buresh and Tian, 1998).

Agroforestry as an unconventional land managing system deals with various global challenges. Hence, agroforestry practices are finding enormous application in many tropical regions and extenuating diminishing agricultural productivity and natural resources. Trees can influence both the supply and accessibility of soil nutrients. Trees represent both conduits through which nutrients cycle and sites for the accumulation of nutrients. Trees develop soil chemical, physical and biological properties in terms of improved soil N and organic matter, percent clay, available phosphorus, higher total nitrogen and inorganic nitrogen, soil pH, organic carbon (OC), cation exchange capacity (CEC) and electrical conductivity (EC), mean moisture content, exchangeable potassium, sodium, calcium and magnesium, available water capacity, declined sand particles, increased clay particles, soil organic carbon (SOC), total nitrogen, total phosphorus and mineral nitrogen. Hence, soil microbial biomass performs as a source and sinks for the plant nutrients contributing a significant role in nutrient cycling and soil organic matter (SOM) dynamics. This is the major cause in plant residue disintegration, nutrient preservation and cycling practices in the soil and considered necessary for soil fertility development. So agroforestry systems are more sustainable to farmers as a soil fertility management device when commercial fertilizers are not available or too expensive and continuous monocropping practices have deleterious effect on fertility of soils leading to degraded lands. Hence, integration of trees into the farmlands is highly recommended. With this background and ideas in view on issues concerned with the soil enrichment and nutrient cycling under agroforestry system, a field experiment on the effect of different fodder tree species on soil chemical properties was studied under agroforestry system.

MATERIALS AND METHODS

The present field investigation was carried out in existing fodder plantation for two years during kharif and rabi seasons of 2018-19 and 2019-20 to study the effect of different fodder tree species on chemical properties of soil under agroforestry system at University of Agricultural Sciences, Dharwad, Karnataka. The experiment was conducted in Kharif and Rabi seasons during 2018-19 and 2019-20 at Dharwad campus which is located at 15° 26' North latitude and 75° 0' East longitude, with an elevation (altitude) of 678 m above mean sea level. The experimental plot is situated in transitional tract, representing Northern Transitional climate zone (Zone 8) of Karnataka (Fig. 1). Soil of the experimental location is medium deep black in nature. The composite soil sample was collected from 0-15 cm soil depth from the site before the initiation of the experiment. The soil samples were air dried, powdered and allowed to pass through 2 mm sieve and were analyzed for chemical properties.

Fig. 1: View of fodder tree species based agroforestry system

Seven fodder tree species *viz*., *Calliandra calothyrsus*, *Albizia lebbeck*, *Leucaena leucocephala*, *Sesbania grandiflora*, *Gliricidia sepium, Moringa oleifera* and *Bauhinia purpurea* were planted during 2014 at a spacing of 5 × 3 m and the plot size was 15 × 12 m with 12 trees per treatment. The experiment was laid out in Randomized Block Design (RBD) with three replications in an established plantation**.** Land was ploughed after the harvest of the previous crop and harrowed twice to crush the clods and brought to fine tilth before sowing intercrops (soybean and safflower). The pruning of fodder tree species was done thrice in year at 2 m height. Annual cultural operations were carried out in fodder based agroforestry system as per the package of practices.

The composite soil samples were collected from 0-45 cm soil depth from the net plots of different fodder trees in three stages *viz*., Before sowing of intercrops, After harvesting of soybean and After harvesting of safflower, from each representative sample plot in all replications from 0-45 cm depth after scraping away the litter before initiation and at the end of the experiment during 2018 and 2019. The soil samples were air dried, powdered and allowed to pass through 2 mm sieve and analyzed for chemical properties by adopting standard procedure *viz*., pH, Electrical Conductivity, Available nitrogen, Available phosphorous, Available potassium, Soil organic carbon, soil moisture and also for secondary and micronutrients of soil such as available sulphur, copper, iron, manganese, zinc and boron using standard procedures.

The statistical analysis was done in simple Randomized Block Design with 8 treatments and 3 replications for the period of 2018-19 and 2019-20 independently. Then the pooled data for both the year (2018-19 and 2019-20) was statistically analysed considering the mean value. The pooled data analysis for both the years was done. Simple correlation (Pearson correlation coefficient) analysis was carried out to study the influence of fodder trees and field crops on soil chemical properties under agroforestry systems.

RESULTS AND DISCUSSION

The land use systems consisting of tree, crops and pastures play a significant role in recuperating soil fertility and its quality by numerous ways. Nair (1984) reported that agroforestry (agri-pastoral) systems have the potential to preserve soil organic matter, improve soil physical properties and boost nitrogen fixation and support efficient nutrient cycling (Table 1).The nutrient content in soil is one of the determining factors for the growth of fodders and forages (Adams and Rieske, 2003). The quality and quantity of fodder are influenced by the type of soil and stage of growth of fodder trees (Anonymous, 1991; Kim *et al*., 2001).

During the present study (2018), soil organic carbon (%) varied significantly after harvesting soybean and safflower crops under fodder tree based agroforestry system with a range of values from 0.439 to 0.975 per cent and 0.783 and 1.007 per cent respectively. Among fodder tree based agroforestry systems, *Gliricidia sepium*+ Soybean (T_5) and *Leucaena leucocephala*+ Safflower (T_3) recorded the highest soil organic carbon (0.975 and 1.007 %)and the least was reported in T_1 - *Calliandra calothyrsus*+ Soybean (0.439%) and in sole crop (0.783 %).

The addition of litter fall and fine root in the soil turnover may increase soil organic matter concentration. The fodder tree based agroforestry systems improved soil conditions by increasing total soil organic matter and biological activity after 6–7 years of establishment. After two years of investigation (2018 and 2019), the soil organic carbon content in the soil under fodder tree based agroforestry systems is in the order of T_3 - *Leucaena leucocephala* + FC (0.776 %) > T_5 - *Gliricidiasepium* + FC (0.774 %) > T_4 - *Sesbania grandiflora* + FC (0.672 %) > T_7 - *Bauhinia purpurea* + FC (0.665 %) > T_2 - *Albizia lebbeck* + FC (0.660 %) > T_6 - *Moringa oleifera* + FC (0.634 %) > T_1 - *Calliandra calothyrsus*+ FC (0.614 % (Table 2). So, organic matter inputs from trees in the form of litter fall and fine roots contributed to increased soil organic matter content. The organic matter content in the soil for different tree species is in the order of Acacia > Populus > Eucalyptus. Similar studies by Kaur (1998) showed that *Acacia nilotica* alone or in combination with crops caused greater improvement of soil organic carbon content closely followed by Populus and Eucalyptus based systems. Further organic matter dynamics studies found that the litter accumulation on the ground floor was higher in Acacia based systems as compared to agroforestry systems with Populus and Eucalyptus (Singh and Gill, 1992; Singh *et al*., 1997; Bhojvaid *et al*., 1996).

Besides litter fall, the fine roots might have contributed to soil organic matter which accounted for more total dry matter input to the soil resulting in higher soil organic carbon. Under the present study, sole crop plot attained lower values of soil organic carbon as compared to fodder trees due to less litter accumulation. Similarly, Yang and Singh (2004) concluded that lower soil organic carbon in agricultural soils was attributed to low organic matter input coupled with reduced physical protection of soil organic carbon as a result of tillage and oxidation of soil organic matter.

In comparison to 2018, there was increase in available nitrogen during 2019 for each treatment under fodder tree based agroforestry systems. This might be due to addition of more litter accumulation during 2018 resulting in more decomposition of litter. The sole crop plot (T_8- control) recorded the highest available nitrogen (254.09, 256.90 and 260.92 kg ha^{-1}) as compared to all agroforestry systems studied. Among fodder tree based agroforestry systems, the treatment *Albizia lebbeck* (T_2) observed higher value of available nitrogen (253.11, 255.87 and 259.09 kg ha^{-1}) and the lowest (231.67, 235.46 and 238.69 kg ha^{-1}) was registered in the treatment T_4 - *Sesbania grandiflora*.

The present data showed that the extent of increase in available nitrogen in soil was 4.72 and 5.86 per cent during 2018 after harvesting soybean and safflower crops respectively in *Gliricidia sepium* + FC (T_5) under fodder tree based agroforestry system compared to before sowing field crops. But in 2019, the extent of increase in available nitrogen was only 1.64 and 3.03 per cent in *Sesbania grandiflora* + FC (T_4) compared to sole crops (Table 2). The contribution of *Gliricidia sepium* + FC (T_5) and *Sesbania grandiflora* + FC (T_4) was more to the available nitrogen in soil due to their leguminous and nitrogen fixing properties as compared to other fodder tree systems.

There was a consistent increase in available nitrogen in soil

Table 1: Soil chemical properties (pH and EC) as influenced by fodder tree based agroforestry systems at different cropping stages

Agroforestry system	2018						2019					
	Before sowing field crops		After harvesting soybean		After harvesting safflower		Before sowing field crops		After harvesting soybean		After harvesting safflower	
	pH	EC (dSm^{-1})	pH	EC (dSm^{-1})	pH	EC (dSm^{-1})	pH	EC (dSm^{-1})	pH	EC (dSm^{-1})	pH	EC (dSm^{-1})
T_1 - *Calliandra calothyrsus*+ FC	6.97	0.090	7.03	0.083	7.45	0.240	7.08	0.095	7.06	0.135	7.40	0.278
T_2 - *Albizia lebbeck* + FC	6.60	0.073	7.11	0.097	7.46	0.277	6.73	0.080	7.12	0.148	7.46	0.282
T_3 - *Leucaena leucocephala* + FC	7.25	0.100	7.13	0.090	7.43	0.390	7.39	0.106	7.15	0.143	7.40	0.395
T_4 - *Sesbania grandiflora* + FC	6.57	0.073	6.95	0.100	6.95	0.383	6.74	0.078	6.97	0.153	6.97	0.398
T_5 - *Gliricidiasepium* + FC	7.05	0.087	6.92	0.100	7.39	0.380	7.19	0.093	6.94	0.151	7.05	0.385
T_6 - *Moringa oleifera* + FC	6.78	0.080	7.03	0.103	7.01	0.367	6.91	0.086	7.06	0.155	7.11	0.372
T_7 - *Bauhinia purpurea* + FC	6.64	0.080	7.03	0.093	6.88	0.480	6.77	0.085	7.04	0.146	6.88	0.430
T_8 - Sole Crop – Soybean - Safflower	6.85	0.077	7.08	0.087	6.92	0.280	6.98	0.083	7.11	0.137	6.92	0.285
SEm ±	**0.227**	**0.007**	**0.190**	**0.008**	**0.050**	**0.013**	**0.231**	**0.008**	**0.191**	**0.010**	**0.131**	**0.020**
CD @ 5%	**NS**	**NS**	**NS**	**NS**	**0.152**	**0.041**	**NS**	**NS**	**NS**	**NS**	**0.402**	**0.061**

FC – Field Crop; Age of the fodder tree plantation – 5 years (2018) and 6 years (2019)

Table 2: Soil chemical properties (Organic carbon and Available nitrogen) as influenced by fodder tree based agroforestry systems at different cropping stages

Agroforestry system	2018						2019					
	Before sowing field crops		After harvesting soybean		After harvesting safflower		Before sowing field crops		After harvesting soybean		After harvesting safflower	
	OC (%)	Available N ($kg\ ha^{-1}$)	OC (%)	Available N ($kg\ ha^{-1}$)	OC (%)	Available N ($kg\ ha^{-1}$)	OC (%)	Available N ($kg\ ha^{-1}$)	OC (%)	Available N ($kg\ ha^{-1}$)	OC (%)	Available N ($kg\ ha^{-1}$)
T_1 - *Calliandra calothyrsus*+ FC	0.467	242.62	0.439	245.26	0.890	249.90	0.648	253.06	0.689	255.49	0.548	258.71
T_2 - *Albizia lebbeck* + FC	0.490	243.56	0.590	247.99	0.990	251.39	0.618	253.11	0.642	255.87	0.628	259.09
T_3 - *Leucaena leucocephala* + FC	0.537	229.29	0.685	232.70	1.007	236.10	0.692	242.19	0.865	245.00	0.868	248.22
T_4 - *Sesbania grandiflora* + FC	0.517	218.42	0.516	222.02	0.867	225.42	0.672	231.67	0.768	235.46	0.692	238.69
T_5 - *Gliricidiasepium* + FC	0.600	218.61	0.975	228.93	0.913	231.42	0.718	241.03	0.730	244.11	0.710	247.33
T_6 - *Moringa oleifera* + FC	0.493	220.20	0.459	229.21	0.827	232.33	0.648	241.46	0.716	244.27	0.658	247.49
T_7 - *Bauhinia purpurea* + FC	0.570	239.15	0.697	240.13	0.800	243.53	0.625	248.22	0.648	251.34	0.648	254.44
T_8 - Sole Crop – Soybean - Safflower	0.583	244.59	0.540	248.25	0.783	251.65	0.638	254.09	0.792	256.90	0.678	260.92
SEm ±	**0.083**	**2.360**	**0.024**	**4.797**	**0.016**	**4.514**	**0.079**	**3.813**	**0.030**	**3.808**	**0.017**	**3.905**
CD @ 5%	**NS**	**7.227**	**0.073**	**14.691**	**0.050**	**13.824**	**NS**	**11.679**	**0.091**	**11.661**	**0.051**	**11.960**

FC – Field Crop; Age of the fodder tree plantation – 5 years (2018) and 6 years (2019)

after harvesting of soybean and safflower crops under fodder tree based agroforestry system as compared to before sowing field crops. This was attributed to incorporation of crop residues after harvesting crops and adding more organic matter and these leguminous fodder tree species under agroforestry system might have also influenced and contributed in the form of litter to gradual increase in available nitrogen in soil. Higher value of available nitrogen under *Albizia lebbeck* (T_2) was attributed mainly to its nitrogen fixing ability with adequate root nodules as compared to other fodder tree species. The results are in agreement with Kadiata and Mulongoy (1995) who reported that *Albizia lebbeck* accumulated significantly more nitrogen than *Leucaena leucocephala* and *Gliricidia sepium*. This superiority in nitrogen yield was due to its abundant nodule dry weight production which accounted up to 10.8 per cent of its total nitrogen. This was equivalent to 2.5 and 6.0 fold of *Gliricidia sepium* and *Leucaena leucocephala* nodules, respectively.

Higher nitrogen availability under agroforestry system may be attributed to high organic inputs from the trees. For certain tropical agroforestry systems, Haggar *et al.* (1993) showed that an efficient uptake of nitrate by trees was more at closer to trees and higher rates of N mineralization close to the trees may be due to the rhizospheric effects. Yadav *et al.* (2008) opined that litter fall and disintegration are the two major aspects leading to soil improvement in agroforestry. There was considerable build up of soil organic carbon and available nitrogen in the agrisilvicultural systems under *Prosopis cineraria*. A study by Singh *et al.* (1989) showed an increase in available nutrients due to mineralization of nutrients from litter fall, fine roots and release of nutrients from the residual soil reserves.

The results revealed that the extent of increase in available phosphorus in soil during 2018 after harvesting soybean and safflower crops was 8.81 per cent in *Calliandra calothyrsus* + FC (T_1) and 23.08 per cent in *Sesbania grandiflora* + FC (T_4) respectively under fodder tree based agroforestry system over the soil collected before sowing field crops. Whereas in 2019, it was 10.95 per cent in *Sesbania grandiflora* + FC (T_4) and 6.66 per cent in *Albizia lebbeck* + FC (T_2) over the soil without crops as compared to control plot (sole crop).This gradual increase in available phosphorus in soil after harvesting soybean and safflower crops under fodder tree based agroforestry system as compared to before sowing field crops was attributed to incorporation of crop residues after harvesting intercrops. This in turn added more organic matter and also these fodder tree species could have contributed due to litter mineralization.

Among the cropping periods, there was depletion in available phosphorus during 2019 as compared to 2018. This might be due to leaching of nutrients through excess rainfall both in kharif and rabi seasons during 2019. This could be the reason for affecting the growth and yield of intercrops during the period. Among the fodder tree systems, *Calliandra calothyrsus* + FC (T_1), *Sesbania grandiflora* + FC (T_4) and *Albizia lebbeck* + FC (T_2) have a greater influence on available phosphorus due to litter mineralization.Under a similar study, Singh and Sharma (2012) observed that available phosphorus was higher under kikar (9.5 mg kg^{-1}) beneath trees as compared to shisham and khair in the surface layer as well as whole soil profile indicating importance of tree plantation in improvement of nutrient availability in the soil profile. Yadav *et al.* (2008) opined that there was significant build up of soil organic carbon and available phosphorus with *Prosopis cineraria* under agrisilvicultural systems.

Ramesh *et al.* (2013) reported that presence of multipurpose tree species (MPTs) (*Michelia oblonga*, *Parkia roxburghii*, *Alnus nepalensis* and *Pinus kesiya*) in Meghalaya (India) improved all the physico-chemical and microbial biomass parameters. Soils under multipurpose tree species showed significant increase of available phosphorus (28 %) as compared to control. In a similar study by Swain (2014) opined that significant increase in the availability of phosphorus was observed in the mango orchard soils with intercropping of legumes. In another study, Shehnaz (2014) noticed an increase in available phosphorus under poplar over control (no tree canopy) in surface layers of soil from 3.4 to 32.8 per cent and opined that poplar was superior to eucalyptus in enriching the soil.

Singh *et al.* (2014) reported that available soil phosphorus was significantly higher under poplar based agroforestry system as compared to open farming system in Uttarakhand resulting a marked improvement of available phosphorus (12.41 %) in agroforestry system over open farming system. In another study, Pellegrino *et al.* (2011) observed an increase in soil available phosphorous by about 30-71 per cent in the triannual cutting cycles of poplar stand as compared to maize-wheat cropping system. Singh *et al.* (1989) showed an increase in available nutrients was due to mineralization of nutrients from litter fall, fine roots and release of nutrients from the residual soil reserves.Among fodder tree based agroforestry systems, *Albizia lebbeck* (T_2) recorded the highest available potassium (266.06, 270.87 and 274.86 kg ha^{-1})and *Sesbania grandiflora* (T_4) has the least values of 225.33, 226.81 and 234.23 kg ha^{-1} as compared to other treatments. However, sole crop plot (T_8 - control) recorded maximum (362.27, 369.70 and 377.03 kg ha^{-1}) as compared to other agroforestry systems (Table 3).

Before sowing field crops during 2019, available potassium (kg ha^{-1}) varied significantly among treatments under fodder tree based agroforestry systems with values ranged from 233.80 to 320.55 kg ha^{-1}. Available potassium (kg ha^{-1}) increased in each treatment from 2018 to 2019 under fodder tree based systems. The sole crop plot (T_8 - control) recorded the highest available potassium (320.55, 326.32 and 330.03 kg ha^{-1}) as compared to other agroforestry systems. Among fodder tree based agroforestry systems, *Albizia lebbeck* (T_2) observed higher values of available potassium (284.89, 295.74 and 303.45 kg ha^{-1}). The lowest value (233.80, 240.56 and 250.55 kg ha^{-1}) was registered in the treatment T_4- *Sesbania grandiflora.*The present results showed that the extent of increase in available potassium in soil during 2018 after harvesting soybean and safflower crops was 3.96 and 7.11 per cent respectively in *Leucaena leucocephala* + FC (T_3) under fodder tree based agroforestry system over before sowing of field crops. However, in 2019, it was 3.81 and 6.51 per cent respectively increase in *Albizia lebbeck* + FC (T_2) over no crops as compared to open control plot.

Available potassium in soil gradually increased after harvesting of soybean and safflower crops under fodder tree based agroforestry system as compared to the soil before sowing field crops. This was attributed to external fertilization to crops and also incorporation of crop residues after harvesting of crops and adding more organic matter and these leguminous fodder tree species under agroforestry systems might have also influenced and contributed in the form of litter to gradual increase in available potassium in soil.But there was no considerable difference in extent of increase in available potassium among the cropping periods studied (2018 and 2019) both in kharif and rabi seasons in sole crops, however, among the fodder tree species, *Leucaena leucocephala* + FC (T_3) and *Albizia lebbeck* + FC (T_2) have greatly influenced potassium content compared to other fodder tree species under agroforestry system.

The study conducted by Singh and Sharma (2012) observed that available potassium was higher under kikar (142 mg kg^{-1}) beneath trees than shisham and khair in the surface layer as well as whole soil profile. Higher available potassium content under trees suggested that tree plantation can improve the nutrient availability in the soil profile. Yadav *et al.* (2008) opined that there was a considerable development of soil organic carbon and available potassium with *Prosopis cineraria* under agrisilvicultural systems. Ramesh *et al.* (2013) reported that soils under multipurpose tree species (MPTs) showed significant increase of available potassium (50 %) than control due to presence of multipurpose tree species *viz*., *Michelia oblonga*, *Parkia roxburghii*, *Alnus nepalensis* and *Pinus kesiya*, in Meghalaya (India) improving all the physico-chemical and microbial biomass parameters. In a similar investigation by Das *et al.* (2017), the maximum available potassium was recorded in Mango + No filler + Cowpea (236.11±26.9 kg ha^{-1}) among the different combinations, whereas the minimum value was recorded in case of Mango + Gamhar + Cowpea (143.87±18.6 kg ha^{-1}). Hence, the depletion in the available potassium can be attributed to higher uptake by the filler plants.

A study by Shehnaz (2014) noticed an increase of available potassium over control (no tree canopy) in surface layers of soil from 5.8 to 24.3 per cent and concluded that poplar was superior to eucalyptus in

Table 3: Soil chemical properties (Available P2O5 and K2O) as influenced by fodder tree based agroforestry systems at different cropping stages

Agroforestry system	2018						2019					
	Before sowing field crops		After harvesting soybean		After harvesting safflower		Before sowing field crops		After harvesting soybean		After harvesting safflower	
	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
T_1 - *Calliandra calothyrsus*+ FC	30.98	254.36	33.71	257.45	35.24	267.53	37.56	279.39	39.46	286.15	41.98	293.56
T_2 - *Albizia lebbeck* + FC	32.31	266.06	33.80	270.87	35.33	274.86	37.99	284.89	40.39	295.74	43.08	303.45
T_3 - *Leucaena leucocephala* + FC	27.31	244.42	28.80	254.09	30.33	261.80	32.66	269.62	34.79	276.38	35.29	284.09
T_4 - *Sesbania grandiflora* + FC	20.88	225.33	22.84	226.81	25.70	234.23	28.03	233.80	31.10	240.56	33.48	250.55
T_5 - *Gliricidiasepium* + FC	21.34	226.91	23.05	228.18	25.90	235.86	28.23	243.68	31.50	252.40	33.99	260.11
T_6 - *Moringa oleifera* + FC	26.73	238.69	28.56	239.04	30.09	246.02	32.41	253.83	33.89	260.60	35.05	268.31
T_7 - *Bauhinia purpurea* + FC	28.25	249.89	30.41	257.33	32.47	264.13	34.13	271.94	36.27	276.95	37.43	284.66
T_8 - Sole Crop – Soybean - Safflower	34.85	362.27	37.91	369.70	39.08	377.03	41.40	320.55	42.88	326.32	44.04	330.03
SEm ±	**1.826**	**11.866**	**1.613**	**13.527**	**1.537**	**11.996**	**1.501**	**6.893**	**1.650**	**6.318**	**1.589**	**6.153**
CD @ 5%	**5.591**	**36.339**	**4.939**	**41.429**	**4.706**	**36.739**	**4.596**	**21.109**	**5.054**	**19.35**	**4.866**	**18.844**

FC – Field Crop; Age of the fodder tree plantation – 5 years (2018) and 6 years (2019)

Table 4: Secondary and soil micronutrients (Available Sulphur and Copper) as influenced by fodder tree based agroforestry systems at different cropping stages

Agroforestry system	2018						2019					
	Before sowing field crops		After harvesting soybean		After harvesting safflower		Before sowing field crops		After harvesting soybean		After harvesting safflower	
	Available S (ppm)	Available Cu (ppm)	Available S (ppm)	Available Cu (ppm)	Available S (ppm)	Available Cu (ppm)	Available S (ppm)	Available Cu (ppm)	Available S (ppm)	Available Cu (ppm)	Available S (ppm)	Available Cu (ppm)
T_1 - *Calliandra calothyrsus*+ FC	12.29	1.89	15.49	1.94	16.39	2.50	14.24	2.05	19.15	2.22	19.16	2.56
T_2 - *Albizia lebbeck* + FC	16.15	2.17	21.49	2.54	19.87	2.20	18.00	2.40	20.19	2.64	22.64	2.25
T_3 - *Leucaena leucocephala* + FC	22.21	2.23	16.35	2.42	20.65	2.20	24.16	2.56	25.42	2.58	21.42	2.25
T_4 - *Sesbania grandiflora* + FC	17.50	2.32	34.43	2.51	22.90	2.16	18.85	2.33	26.09	2.62	25.66	2.21
T_5 - *Gliricidiasepium* + FC	16.30	2.00	26.33	2.24	32.95	2.21	18.58	2.33	17.99	2.38	25.70	2.28
T_6 - *Moringa oleifera* + FC	23.10	2.33	34.87	3.23	25.44	2.64	24.25	2.33	21.52	3.32	28.21	2.71
T_7 - *Bauhinia purpurea* + FC	17.84	2.13	32.25	3.33	24.09	2.51	19.79	2.46	23.92	3.44	26.91	2.57
T_8 - Sole Crop – Soybean - Safflower	24.20	2.94	25.60	4.26	27.47	2.90	26.00	2.99	31.27	5.34	30.26	4.96
SEm ±	**3.771**	**0.433**	**0.596**	**0.172**	**0.635**	**0.026**	**3.775**	**0.435**	**0.591**	**0.182**	**0.633**	**0.033**
CD @ 5%	**NS**	**NS**	**1.825**	**0.526**	**1.944**	**0.080**	**NS**	**NS**	**1.810**	**0.557**	**1.938**	**0.101**

FC – Field Crop; Age of the fodder tree plantation – 5 years (2018) and 6 years (2019)

Table 5: Soil micronutrients (Available Iron and Manganese) as influenced by fodder tree based agroforestry systems at different cropping stages

Agroforestry system	2018						2019					
	Before sowing field crops		After harvesting soybean		After harvesting safflower		Before sowing field crops		After harvesting soybean		After harvesting safflower	
	Available Fe (ppm)	Available Mn (ppm)	Available Fe (ppm)	Available Mn (ppm)	Available Fe (ppm)	Available Mn (ppm)	Available Fe (ppm)	Available Mn (ppm)	Available Fe (ppm)	Available Mn (ppm)	Available Fe (ppm)	Available Mn (ppm)
T_1 - *Calliandra calothyrsus*+ FC	9.00	2.90	10.62	4.18	19.46	16.58	8.49	3.77	12.55	4.54	20.36	8.50
T_2 - *Albizia lebbeck* + FC	8.61	1.87	9.29	2.50	18.24	11.07	9.44	2.11	15.22	3.84	19.33	9.65
T_3 - *Leucaena leucocephala* + FC	9.58	3.33	11.75	4.77	16.44	18.46	9.41	2.44	15.70	9.10	18.55	10.25
T_4 - *Sesbania grandiflora* + FC	6.80	2.12	8.31	3.01	20.04	21.70	9.63	2.47	15.20	4.36	21.13	13.44
T_5 - *Gliricidiasepium* + FC	6.70	1.85	9.96	4.94	18.36	14.31	9.53	2.29	16.88	5.27	19.46	11.08
T_6 - *Moringa oleifera* + FC	8.61	3.33	11.50	5.89	24.85	22.87	10.22	3.62	20.42	8.20	17.94	14.61
T_7 - *Bauhinia purpurea* + FC	7.75	3.73	12.17	6.41	23.11	18.07	10.26	4.17	21.92	8.73	18.34	19.83
T_8 - Sole Crop – Soybean - Safflower	6.65	3.38	17.45	10.01	31.04	26.94	7.48	6.52	22.40	11.33	32.15	18.67
SEm ±	**1.938**	**0.936**	**0.536**	**0.608**	**0.254**	**0.257**	**0.649**	**0.776**	**0.503**	**0.602**	**0.258**	**0.259**
CD @ 5%	**5.936**	**NS**	**1.642**	**1.863**	**0.778**	**0.788**	**1.988**	**2.377**	**1.539**	**1.844**	**0.790**	**0.792**

FC – Field Crop; Age of the fodder tree plantation – 5 years (2018) and 6 years (2019)

enriching the soil. Similarly, Singh *et al.* (2014) reported that available potassium was significantly higher (6.20 %) with marked improvement under poplar based agroforestry system as compared to open farming system in Uttarakhand. Vishwanath (2013) reported that the soil fertility was significantly better in association with biofuel trees compared to open field in Bengaluru in which available potassium (304.67 kg ha^{-1}) was significantly higher under agroforestry system.

The study showed available nutrients increased due to mineralization of nutrients from litter fall, fine roots and release of nutrients from the residual soil reserves (Singh *et al.*, 1989). A similar study conducted by Gindaba *et al.* (2005) concluded that *Croton macrostachyus* and *Cordia africana* trees on farms keep soil nutrient high via protection against leaching, translocation of nutrients from deeper to the surface layer and accumulation of litter, which create a temporary nutrient pool in the surface soils under their canopies. Similar results were also established under alley cropping agroforestry systems.

Soil micronutrients are important elements for plant growth but required in small quantities. Deficiency of micronutrients can result in severe crop failure while excess levels can lead to health hazards. Therefore, investigating status of micronutrients in soil under agroforestry systems is crucial. The soil micronutrients are relatively in small amounts and soil supplies sulphur, iron, manganese, boron, molybdenum, copper, zinc, chlorine and cobalt which are known as soil micronutrients. The main sources of soil micronutrients are inorganic forms from parent material and organic forms within humus, though deficiency or toxicity can mostly be attributed to the parent material (Ritchie *et al*., 2007; Joy *et al*., 2015).

The available sulphur as secondary nutrient indicates elemental sulphur and other forms as found in soil organic matter. They must be converted to the sulfate (SO_4) form to become available to the crop. This sulphur is available to crops when the roots reach this area of the soil. In the present study, available sulphur of soil after harvesting soybean crop was recorded maximum in T_6 - *Moringa oleifera* + Soybean (34.87 ppm in 2018) and T_4 - *Sesbania grandiflora* + Soybean (26.09ppm in 2019). Whereas, available sulphur in soil after harvesting safflower observed highest in T_5 - *Gliricidia sepium*+ Safflower (32.95 ppm in 2018) and T_6 - *Moringa oleifera* + Safflower (28.21ppm in 2019) (Table 4).

Copper availability depends on organic matter and soil pH, and copper accessibility declines as soil organic matter increases. Organic matter binds copper more firmly compared to other micronutrients. After harvesting soybean, available copper (ppm) in soil was highest in T_7 - *Bauhinia purpurea* + Soybean agroforestry system (3.33 and 3.44ppm respectively in 2018 and 2019). But after harvesting safflower, maximum values were noticed in T_6 - *Moringa oleifera* + Safflower agroforestry system (2.64 and 2.71ppm in 2018 and 2019 respectively).

Available iron is the fourth most abundant element found in soil though it is largely present in forms that cannot be taken up by plants. In small amounts, iron is essential for healthy plant growth. Organic matter provides iron and makes it more readily available. After harvesting soybean during the periods of investigation, *Bauhinia purpurea* + Soybean (T_7) agroforestry system recorded higher values of 12.17and21.92ppm available iron in soil during 2018 and 2019 respectively. After harvesting safflower crop, T_6 - *Moringa oleifera* + Safflower and T_4 - *Sesbania grandiflora* + Safflower (24.85 and21.13 ppm) noticed highest values during 2018 and 2019 respectively (Table 5).

Manganese is available in soil pH lower than 7.0 but its toxicity might occur at soil pH lower than 5.5 whereas at a higher soil pH, manganese solubility is reduced. In fact, manganese deficiency is more common in soils with high organic matter content than in alkaline soils. After harvesting of soybean during the study periods, the highest available manganese in soil was recorded in T_7 - *Bauhinia purpurea* + Soybean (6.41ppm) and T_3 - *Leucaena leucocephala* + Soybean (9.10 ppm) respectively. After harvesting safflower, maximum values were recorded in T_6 - *Moringa oleifera* + Safflower (22.87ppm)andT_7 - *Bauhinia purpurea* + Safflower (19.83ppm) (Table 5).

Available zinc (ppm) in soil was insignificantly influenced by fodder tree based agroforestry systemsbefore sowing of field crops but varied significantly after harvesting field crops (soybean and safflower) during 2018 and 2019. Available zinc is one of the eight essential micronutrients and it is needed by plants in small amount but crucial to plant development. After harvesting of soybean, available zinc (ppm) in soil attained highest in T_7 - *Bauhinia purpurea* + Soybean (1.600ppm in 2018) and T_6 - *Moringa oleifera* + Soybean (1.162ppm in 2019). But after harvesting safflower, the maximum available zinc (ppm) in soil was recorded in T_7 - *Bauhinia purpurea* + Safflower (0.850and 0.979ppm respectively during 2018 and 2019) (Table 6).

Available boron helps to control the transport of sugars in plants. It is important for cell division and seed development. As a micronutrient, the amount of boron in soil is minute, but among micronutrients, boron deficiency in plants is the most common. Available boron (ppm) in soil after harvesting soybean was highest in T_3 - *Leucaena leucocephala* + Soybean (0.375ppm) and (0.435 ppm) agroforestry system. After harvesting safflower, the highest available boron (ppm) in soil was recorded in T_3 - *Leucaena leucocephala*+ Safflower (0.777ppm in 2018) and T_4 - *Sesbania grandiflora* + Safflower (0.612 ppm in 2019) agroforestry systems (Table 6).

The present results indicated that most of the micronutrients studied did not varied significantly before sowing field crops under fodder tree based agroforestry systems, but increased after harvesting (soybean and safflower). Results showed that fodder tree species studied *viz*., *Moringa oleifera, Bauhinia purpurea, Leucaena leucocephala* and *Sesbania grandiflora* with field crops (soybean and safflower)contributed more to soil micronutrients. This could be due to incorporation of more litter to soil after harvesting field crops under agroforestry systems. This might be attributed to favourable pH and organic matter through parent material and organic forms within humus. A study by Murphy *et al.* (2008) and Ali (2014) reported the factors which play important role in regulating micronutrients include soil pH, oxidation state, organic matter, mycorrhizae and organic compounds.

The possible reasons for low micronutrients could be due to unfavourable soil pH, intensive cropping, the use of high yielding varieties, and unsuitable fertilizer application strategies practiced by small land holding farmers (Panday *et al*., 2018). As legume constitute a major crop share, the lower boron affects the nodulation in legume plants and can greatly reduce yield (Andersen, 2007; Shrestha *et al*., 2005). Improper use of fertilizer practices and mismanagement of land resources have been accelerating deficiencies of micronutrients. In a similar study, Bhola and Mishra (1998) reported that available zinc, copper, iron and manganese in soil were significantly higher under the Nitrogen Fixing Trees (NFTs) at all peripheral distances as well as soil depths than controls (open plots adjacent to plantation plots). A declining trend in amount of available nutrients was observed towards greater peripheral distance and soil depth. The maximum build up of available copper, iron and manganese was noticed under *A. nilotica* and the maximum zinc was observed under *A. lebbeck*.

The mean organic carbon levels under the canopies of peltophorum and combretum were 47 per cent and 55 per cent higher than in the open grassland of South Eastern Botswana. Exchangeable potassium, magnesium, calcium and CEC were 66–106 per cent higher than their respective levels in the open grassland (Aweto and Dikinya, 2003). In another study by Singh *et al.* (2011), the influence of three tree species *viz*. dek, shisham and eucalyptus was assessed on the available micronutrients in the soil profile up to 120 cm depth. They found that the micronutrient accumulation in soil profile was higher under the tree species as compared to control. The available zinc, iron, manganese and copper decreased significantly with increase in depth. These were higher under dek and eucalyptus than shisham and control at two different sites. Also, the content of manganese was the highest and that of copper the lowest in control or under tree species among four micronutrients. In another study, Singh *et al.* (2007) also reported that zinc, iron, manganese and copper (0.473, 7.77, 1.05 and 0.116 kg ha^{-1}, respectively) were recorded under poplar and returned to soil through litter fall in 5 year old plantation.

CONCLUSION

The fodder tree based agroforestry system improved soil conditions by increasing soil organic matter, available soil nitrogen, phosphorus, potassium and biological activity after 5 to 6 years of establishment of fodder tree based agroforestry systems. Among agroforestry systems, *Gliricidia sepium*+ Soybean (T_5) and *Leucaena leucocephala*+ Safflower (T_3) recorded the highest soil organic carbon. After two years of investigation (2018 and 2019), the organic carbon content in the soil under fodder tree based agroforestry systems was in the order T_3 - *Leucaena leucocephala* + FC > T_5 - *Gliricidia sepium* + FC > T_4 - *Sesbania grandiflora* + FC > T_7 - *Bauhinia purpurea* + FC > T_2 - *Albizia lebbeck* + FC > T_6 - *Moringa oleifera* + FC > T_1 - *Calliandra calothyrsus*+ FC. Soil macro nutrients *viz*., available nitrogen, available phosphorus and available potassium recorded before sowing and after harvesting field crops during the period of investigation were significantly influenced by fodder tree based agroforestry system. The highest available nitrogen, available phosphorus and

Table 6: Soil micronutrients (Available Zinc and Boron) as influenced by fodder tree based agroforestry systems at different cropping stages

Agroforestry system	2018						2019					
	Before sowing field crops		After harvesting soybean		After harvesting safflower		Before sowing field crops		After harvesting soybean		After harvesting safflower	
	Available Zn (ppm)	Available B (ppm)	Available Zn (ppm)	Available B (ppm)	Available Zn (ppm)	Available B (ppm)	Available Zn (ppm)	Available B (ppm)	Available Zn (ppm)	Available B (ppm)	Available Zn (ppm)	Available B (ppm)
T_1 - *Calliandra calothyrsus*+ FC	0.145	0.070	0.599	0.067	0.647	0.470	0.160	0.085	0.618	0.128	0.649	0.362
T_2 - *Albizia lebbeck* + FC	0.120	0.103	0.574	0.356	0.560	0.440	0.131	0.122	0.593	0.415	0.566	0.532
T_3 - *Leucaena leucocephala* + FC	0.081	0.230	0.783	0.375	0.487	0.777	0.096	0.245	0.803	0.435	0.392	0.568
T_4 - *Sesbania grandiflora* + FC	0.030	0.173	0.636	0.298	0.383	0.520	0.040	0.188	0.656	0.357	0.390	0.612
T_5 - *Gliricidiasepium* + FC	0.067	0.053	0.706	0.261	0.283	0.427	0.082	0.068	0.724	0.320	0.291	0.519
T_6 - *Moringa oleifera* + FC	0.190	0.103	1.443	0.237	0.447	0.517	0.202	0.122	1.162	0.300	0.854	0.607
T_7 - *Bauhinia purpurea* + FC	0.049	0.077	1.600	0.258	0.850	0.437	0.064	0.092	1.118	0.320	0.979	0.528
T_8 - Sole Crop – Soybean - Safflower	0.458	0.067	1.330	0.864	1.460	0.370	0.471	0.085	1.348	0.460	1.209	0.461
SEm ±	**0.100**	**0.050**	**0.025**	**0.015**	**0.010**	**0.009**	**0.100**	**0.050**	**0.025**	**0.015**	**0.010**	**0.009**
CD @ 5%	**NS**	**NS**	**0.077**	**0.045**	**0.030**	**0.027**	**NS**	**NS**	**0.078**	**0.045**	**0.032**	**0.028**

FC – Field Crop; Age of the fodder tree plantation – 5 years (2018) and 6 years (2019)

available potassium were found to have maximum in soybean as a sole crop (T_8 - Control), whereas, among agroforestry systems, the treatment *Albizia lebbeck* + Soybean showed highest value of soil macronutrients before sowing and after harvesting field crops during study periods.

CONFLICT OF INTEREST

All the author both individually and collectively, affirms that they do not possess any conflicts of interest either directly or indirectly related to the research being reported in the publication.

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