RESTORATION OF DEGRADED SODIC SOILS THROUGH SILVIPASTORAL SYSTEMS IN INDO-GANGETIC PLAINS

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ABSTRACT

Excessive amount of salts have an unfavorable effect on soil physico-chemical and biological properties in sodic soils. Present study was conducted to analyze the role of silvipastoral systems to improve soil physico-chemical and microbial properties for restoration of degraded sodic soils and maintaining soil fertility. The silvicultural systems characterized by tree species of *Acacia nilotica*, *Casuarina equisetifolia* and *Eucalyptus tereticornis* planted during 1995 at ICAR-Central Soil Salinity Research Institute, Research farm, Shivri, Lucknow (26^0 48'N, 80^0 46' E, 120m.s.l.) in a highly sodic soil (pH 10.6, EC 1.43 $dSm^{-1}$and ESP 89 were used for silvipastoral system during 2005 after 10 years of tree growth with plantation of grass species of *Chloris gayana*, *Panicum maximum* and *Pennisetum purpureum*. Maximum growth and yield of understory grasses was recorded from *Acacia nilotica*+ *Chloris gayana* silvipastoral system. The highest positive correlation between PAR and fodder yield was recorded under treatment T_4. Among the grass species, the highest nutritive value in terms of N.P, K and crude protein contents was recorded in *Pennisetum purpureum* however, highest neutral detergent fiber (NDF) and acid detergent fiber (ADF) in treatment T_4 and T_{11} respectively. The N.P, K and Na^+ uptake in treatment T_4 and T_{10} was significantly higher over rest of the treatments. Significantly higher tree growth and biomass yield was recorded under silvipastoral system over the silvicultural system. A significant decline in soil bulk density and increase in soil porosity, infiltration rate and water holding capacity was recorded under treatment T_7, T_7, T_7 and T_4 respectively which was attributed to reduced sodicity, addition of leaf litter, and increase in microbial activities due to tree and grass roots, better plant growth, and fine root decay. Decline in soil pH, EC, ESP and increase in organic carbon was recorded under treatment T4 silvipastoral system which may be attributed to more release of CO_2 by grass roots and solublization of $CaCO_3$. The microbial biomass carbon under silviculture systems was lower than the silvipastoral systems. The highest MBC was recorded in treatment T_7 which was 302.8% higher over T_{13} (control) which was attributed to ameliorative effect of tree and grasses on soil conditions, increase in organic carbon content in the soil and higher amount of readily available organic compounds from the roots that play important role in the maintenance energy of microbial populations. The highest MBN was recorded under treatment T_4 however, highest MBP (21.6 $\mu g\ g^{-1}$) was recorded in treatment T_7. The highest dehydrogenase activity (6.5TPF $g^{-1}\ h^{-1}$) was recorded in treatment T_4 and the lowest (2.13 TPF $g^{-1}\ h^{-1}$) with T_{13}. This may be due to addition of organic matter and more biological activities in the rhizosphere zone. On the basis of improvement in soil physico-chemical and biological properties in the tree + grass systems, *A.nilotica* + *C. gayana* silvipastoral system could be highly ameliorative and biomass producing system for restoration of degraded sodic soils of Indo-Gangetic plains.

KEY WORDS: Degraded sodic soil; agroforestry systems; fuel and fodder production; tree biomass; soil amelioration

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INTRODUCTION

Land degradation is a major environmental problem for affecting current livelihood as well as the prospects for future development. Land degradation corrodes the three pillars of sustainable development i.e. environmental, social and economic sustainability. To feed more than 7 billion people-nearly 10 billion by 2050 even after becoming resources scares is a daunting challenge to researchers and policy planners (FAO, 2016). Nearly 24% of the world's land area including more than a fifth of the crop land and a third of the forest is degrading and about 1.5 billion people are depending on these degraded lands. Salt affected soils are a major part of degraded lands contributing about 930 million ha to 1.2 billion ha globally (Qadir *et al.,* 2014; Ahmad *et al.,* 2016). The problem of salinity is projected to increase due to present and future climate change scenario like rising in sea level will impact on coastal areas and rising in temperature will increase evaporation resulting salinization. Millions of hectares of these salt affected soils are suited for agricultural production but are unexploited because of salinity/sodicity and other soil and water related problems Abrol *et al*., (1988). Salt-affected soils are reported to comprise 42.3% of the land area of Australia, 21.0% of Asia, 7.6% of South America, 4.6% of Europe, 3.5% of Africa, 0.9% of North America and 0.7% of Central America (El-Mowellhey, 1998). In India out of 329 million ha geographical land area of the country, about 175 million ha suffers from different problems and is getting further degraded through natural or man-made processes. Majority of these lands is treated as wastelands as their productivity is low due to soil based constraints like water logging, salinity and sodicity. According to FAO, 2016, salinization of arable land will result in 30% to 50% land loss in the next 25 years to year

2050 if remedial actions are not taken. Recent estimates indicated that about 6.74 million ha (Mandal *et al.,* 2009) land is suffering from salinity and sodicity problems in India. The major portion (2.7 million ha) of this land is in Indo-Gangetic plain zone comprised of Punjab, Haryana, Uttar Pradesh, part of Bihar (north), West Bengal (south), and Rajsthan (north) states in India lies between 21° 55′ to 32° 39′ N and 73° 45′ to 88° 25′ E (Figure 1 & 2). Restoring this land involves a wide range of approaches: from reforestation, to agricultural interventions to minimize the extent of these lands. The farmers in the Indo-Gangetic plains have put their efforts to reclaim these lands through traditional reclamation practices and cultivating rice-wheat cropping system, but the productivity is very low. In addition to that, a large part of community lands either government lands or village common lands are not in any productive use. In addition to this, a large part of salt affected soils belonging to the individual farmers is lying unproductive (Singh, 2009). Agroforestry strategies have the potential to rehabilitate degraded sodic lands to support livelihoods, improve food security, and help to resource poor farmers who are unlikely to have the resources to restore degraded sodic lands through costly chemical amendments. Judicious use of these lands can substantially contribute in meeting out the increasing demands of food, fodder, fuel and timber, improve food and nutritional security and improve livelihood security of resource poor farmers of this degraded ecosystem in the country. The production potential of these lands can be improved by protecting natural vegetation (Gupta *et al.,* 1990). Plantation of trees alone (silviculture) or in combination with grasses (silvipastoral) have been found promising to restore degraded sodic lands by improving physico-chemical and microbial properties (Rao and Pathak, 1996; Kaur *et al.,* 2002, Singh *et al.,* 2010, Singh *et al.,* 2011, Sharma *et al.,* 2014). Several studies have been reported that the biological activities of sodic soils can be improved by growing of certain salt tolerant grass and tree species (Rao and Ghai, 1985; Kumar, 1996) but most of the studies are confined to newly established silvipastoral agroforestry systems. In this study salt tolerant grass species were grown under ten year old salt tolerant tree species like *Acacia nilotica*, *Casuarina equisetifolia* and *Eucalyptus tereticornis* to analyze the effect of integration of grass species on biomass production to meet the increasing demand of fuel and fodder and improvement in soil physico-chemical and biological properties.

MATERIALS AND METHODS

Site description

This study was conducted in ten year old plantation of *Acacia nilotica* delile sub sp. Indica (Benth.) Brenan, *Casuarina equisetifolia* (Linn.), and *Eucalyptus tereticornis* sm, planted on a highly sodic soil (pH 10.6, EC 1.43 dS m^{-1}, ESP 89) at Central Soil Salinity Research Institute (CSSRI), Research Farm, Shivri, Lucknow (26^0 48'N, 80^0 46' E, 120m.s.l.), India. The analysis of surface soil (0-15cm depth) displayed physical and nutritional problems, high bulk density, poor infiltration, strongly alkaline with a predominance of carbonate and bicarbonate of Na^+. The details of initial soil properties are given in table I.

The climate of the study site is semi-arid, subtropical and monsoonic receiving an average annual rainfall of 817mm (1995-2005). Maximum rainfall is received between 23 to 40 standard weeks (June to October) amounting to 741mm, which is 91% of the total annual rainfall. The remaining 9% rainfall is received between 41 to 19 standard weeks (November to May). The average annual evaporation is 1580mm. The evaporation rate gradually increased with increasing air temperature and atmospheric water demands from 1 to 22 weeks and it decreased following rains and decreasing temperature. The mean maximum temperature of 39°C in the month of May and mean minimum of 7.1^{0}C in the month of January indicate a season climate (Figure 3).

Experimental details

To analyze the effects of agroforestry systems on growth, biomass yield and quality of grasses and improvement in soil physico-chemical and biological properties, a field experiment with thirteen treatments comprised of three silviculture treatments *viz.* T_1- *A. nilotica,* T_2- *C. equisetifolia,* T_3- *E. tereticornis,* nine silvipastoral treatments viz. T_4- *A. nilotica+ C. gayana,* T_5- *A. nilotica+ P. maximum,* T_6- *A. nilotica + P. purpureum,* T_7- *C. equisetifolia+ C.gayana*,T_8- *C. equisetifolia + P. maximum,* T_9- *C. equisetifolia + P.purpureum,*T_{10}- *E. tereticornis+ C. gayana,*T_{11}- *E. tereticornis + P. maximum,* T_{12}- *E. tereticornis + P. purpureum* and one T_{13}-control (barren and undisturbed) plot where no agroforestry system was initiated during 2005. Three times replicated field experiment was conducted in split plot design. The tree species used for this study were planted during 1995 at 4m x 3m row to row and plant to plant spacing. Before plantation of understory grasses, tree growth in terms of height, diameter at breast height (DBH), diameter at stump height (DSH), crown diameter and biomass yield were measured (Table 2). To get sufficient sunlight to the understory grass species and to stimulate tree growth, pruning of side branches of trees up to one third of the total stem length was done (Singh *et al.,* 1989) and the data of pruned biomass was recorded. The photo synthetically active radiation (PAR) measured four times (winter, spring, summer and autumn) before harvesting of fodder grasses under tree species was derived by multiplying the solar radiation with 0.47 (Akmal *et al.,* 2010). The root slips of *C. gayana (Rhodes grass)*, *P. maximum (*guinea grass) and *P. purpureum (*elephant grass) were planted during July 2005 in between tree rows at 50cm x 50cm row to row and plant to plant spacing. Recommended agronomic practices for cultivation of these grass species were followed. The irrigation water applied to the grasses was analyzed following standard methods and found of good quality (pH 8.2, EC 0.63dSm^{-1}, residual sodium carbonate (RSC) 2.80 Meq l^{-1}, Na 3.2 me l^{-1}, K 0.1 me l^{-1} and Cl 1.5 me l^{-1}). To monitor the effect of agroforestry systems over the control (natural fallow), a 600m^2 (12m x 50m) plot was kept barren adjacent to the experimental field.

Growth and Biomass Yield of Tree and Grasses

To measure plant growth and biomass, three trees in each species representing all size variations were selected, marked to measure plant height, DBH, DSH and crown diameter and uprooted at the end of the experiment (2008) and the data were reported on an average basis. To measure component wise air dry biomass, stem, branch, leaves and roots were separated and weighed on dry weight basis using a stratified sampling procedure. To monitor the tolerance level of different grass species, observation on mortality percentage were taken from 10m^2 (5x2m) grid in each replication after 30, 60 and 90 days of transplanting. To measure the growth of understory grass species, ten plants of each grass species in each replication were tagged to measure plant height and number of tillers $hill^{-1}$. Plant height was measured from ground surface to the top of the plant and averaged. Leaf area index (LAI) was recorded nondestructively using leaf area machine (LI-2000, LI-COR, USA). To measure green fodder yields, all the grass species were harvested manually at 90 days interval from gross plot (48m^2) area in each replication with a total area of 144m^2 (48x3m), weighed individually on the same day, averaged and reported in Mg ha^{-1}.To measure dry biomass yields, green fodder grasses harvested from the quadrates (Shetty and Singh, 1993) marked at three places under each species in all three replications, sundried for 3 days and then oven dried for 5 days at 50^{0}C± 1^{0}C, weighed and reported in kg ha^{-1} year^{-1}. To monitor Shoot: root ratio of grass species, three tagged plants under each replication were allowed to grow for one year. After one year roots were completely removed from the ground by digging a trench and washed gently through tap water, collected in a sieve and dried in oven at 65^{0}C± 1^{0}C till constant weight.

Quality of grass species

To analyze the quality of grass species, about 450 g biomass of each grass species was collected from the plants which were not damaged by any insect or disease at full bloom stage. Whole plant samples were sterilized with 2% sodium hypochlorite solution for 15 minutes and washed with distilled water, dried at 55°C for 48 hours and stored at room temperature (Ates, 2016). All dried samples were ground through a 1 mm screen (Abraham, 2014). For forage quality analysis, the contents of crude protein (CP), neutral detergent fiber (NDF) and acid detergent fiber (ADF) were considered according to procedures described by Rodrigues (2010). N was determined by the Kjeldahl method and was used for crude protein calculation, multiplying by factor 6.25 (Silva and Queiroz, 2006). After plant samples were wet-fired with nitric-perchloric acid and phosphorus (P) content was determined spectro-photometrically. The potassium (K) analyzed using an atomic adsorption spectrophotometer. Samples were analyzed for N content using the Kjeldahl procedure (AOAC 2007).

Soil Sampling and Analysis of Soil

To analyze the effect of silviculture and silvipastoral systems on soil physico-chemical and microbial properties, soil samples were collected after three years of experiment from each treatment plots. For making a representative sample, five sample were collected along a transect joining the rows of trees and clumps of grasses from each of the tree replication of thirteen treatments. The samples were brought to the laboratory in polyethylene bags and stored at 4°C until analysis. The samples were air dried and ground in a willey mill and passed through a 2.0mm sieve. The bulk density of different soil layers was determined from intact cores extracted with a core sampler of 10 cm in diameter and 15 cm length (Wilde *et al.,* 1964) by weighing a known volume ($100m^3$) of undisturbed soil sample. Water holding capacity and soil porosity were determined by the method described by Brady (1990). The Infiltration rate was measured by double concentric infiltrometer cylinders with 60 cm outer and 30 cm inner diameters (Fatehnia *et al.,* 2016). Soil pH_2 (1:2 soil: deionized water) and electrical conductivity (EC_2) determined with digital meters (pH meter 361-Systronics India Ltd, Ahmadabad and Lab-960, SI Analytics GmbH, Germany). However, ESP was calculated from the formula described by Richards, 1954.The organic carbon was measured by ignition (Wang *et al.,* 1996) method where approximately 2 g of dry soil (sieved to <2.0 mm) was placed in ceramic crucibles in a muffle furnace at 375^0C for 16 hours. Available N content was estimated by distillation of soil with $KMnO_4$ and NaOH (Subbiah and Asija 1956). Available P and K were determined by the Olsen's sodium bicarbonate extraction method (Olsen and Dean 1965) and sodium acetate extraction method, respectively. Exchangeable cations (Na^+, K^+, Ca^{++} and Mg^{++}) were extracted from the soil with neutral normal ammonium acetate solution and the concentration of Na^+ and K^+ was determined by flame photometer while Ca^{++} and Mg^{++} was determined through titration following the method described by Jackson, 1967.

The analysis of soil microbial biomass carbon (MBC), microbial biomass nitrogen (MBN) and microbial biomass phosphorus (MBP) was completed within ten days using sieved samples following fumigation extraction method (Vance *et al.,* 1987). The sieved soil samples (50g oven dry) were fumigated with alcohol free chloroform in vacuum desiccators' and stored in the dark for 24 hour. After removing the fumigant, the soil samples were extracted with 200ml 0.5 M K_2SO_4 for 30 min on a shaker. The soil extracts of both fumigated and unfumigated samples were analyzed for organic carbon using the acid dichromate method (Vance *et al.,* 1987). Soil microbial biomass carbon (MBC) was estimated as MBC = 2.64 EC, (Vance *et al.,* 1987), where EC (extractable carbon) is the difference between carbon extracted from fumigated and unfumigated samples. Microbial biomass nitrogen (MBN) was calculated as BN=EN/0.54 where EN (extractable N) is the difference between N extracted from fumigated and unfumigated samples. Dehydrogenase activity was analyzed using the method developed by Casida *et al.*, 1964.

Statistical analysis

Data for various growth parameters and yield related traits of both silviculture and silvipastoral systems and soil improvement were subjected to statistical analysis and presented as means of corresponding replicates. Analysis of variance (F test) was applied to examine the significance of differences among the treatments. Critical difference among the treatments was determined using AGRES Statistical Software Version 3.01. The treatment comparisons were made using t-tests at the 5% level of significance.

RESULTS AND DISCUSSION

Growth and Yield of Understory Grasses

Plant mortality in grass species after 30 days of transplanting (DAT) ranges from 23.92-45.40%. The highest mortality (45.40%) was recorded in *P. purpureum* planted under *C. equisetifolia* (T_9) which was significantly higher over rest of the treatments whereas, minimum (23.92%) with *C. gayana* under *E. tereticornis* (T_{10}). Similar trend was observed at 60 and 90 DAT. This may be due to less canopy cover and more light received under *E. tereticornis.* The *C. gayana* attains maximum plant height under all the tree species (3 years average) whereas, minimum with *P. purpureum*. The *C. gayana* planted under *E.tereticornis* (T_{10}) attained significantly higher plant height over rest of the treatments but at par with treatment T_4 and T_{11} (Table III). Number of tillers hill^{-1} under different treatments ranges from 5.40 to 32.90. Maximum number of tillers hill^{-1} in all grass species were recorded under *E. tereticornis* whereas, minimum under *C.equisetifolia. C. gayana* planted under treatment T_{10} produced significantly higher number of tillers hill^{-1} over rest of the treatments but at par with treatment T_4. The PAR affected number of tillers in understory grasses. Low PAR reduces photo assimilate supply which inhibits the production of new tillers (Difante *et al.,* 2011). Highest leaf area index (1.95) was recorded with treatment T_6 and the lowest (1.16) with T_7. The leaf area index of *P.purpureum* planted under all the three tree species was significantly higher over *C. gayana* and *P.maximum.* Root: shoot ratio of grass species under different treatments ranges from 2.2 to 3.92. Maximum shoot: root ratio (3.92) was recorded with treatment T_4 and the lowest (2.25) with T_8. The shoot: root ratio under treatment T_4 was significantly higher over rest of the treatments except treatment T_{10} (Table 3). This is because of more number of tillers in *C. gayana* under *A.nilotica* than the *P.maximum* and *P. purpureum* and high litter fall of *C. equisetifolia* leaves which made a thick mat of un-decomposed material resulting poor grass growth (Singh *et al.,* 2014). The lower incidence of PAR increased average canopy height and the length of petioles, stems and leaf blades (Gobbi *et al.,* 2009).

Fodder yield is an important parameter for the evaluation of sustainability of the silvipastoral system. From the data presented in figure 4 it is evident that the understory grass yields under silviculture, silvipastoral and control treatments increased with increasing time of harvesting. The maximum annual average fodder yield during three consecutive years was recorded in treatment T_4 whereas, the minimum with T_{13}. The natural grass yield obtained from the underneath of silviculture tree species (T_1, T_2 and T_3) and from control (T_{13}) was significantly lower than the fodder grasses grown under silvipastoral systems. Maximum natural grass yield (747.5kg ha^{-1} $year^{-1}$) during first year of experiment was obtained under *E.tereticornis* whereas during second and third year it was highest under *A.nilotica*. It may be due more improvement in soil properties under *A.nilotica* as compared to *E.tereticornis*. Fodder yield of *C. gayana* under silvipastoral system during three consecutive years was significantly ($p>0.05$) higher over fodder yield of *P.maximum* and *P.purpureum.* Total fodder yield from 12 harvesting during 3 years period (39587.5kg ha^{-1}) obtained from treatment T_4 was 27.70 and 12.46% higher over the treatment T_7 and T_{10}. The highest annual increment in grass yield over a period of three years was recorded in treatment T_{10} followed by T_7 and T_4. From the data it is also observed that the yield of natural grasses under control (T_{13}) was significantly lower than that of natural grass regenerated under the tree canopy. This is because of higher improvement in soil pH and organic carbon under the trees (Figure 4).

From the study it was observed that in addition to soil properties, the PAR plays an important role in growth and yield of understory grasses. In this study average PAR ranged from 1.52 to 8.54 MJ m^{-2} y^{-1}. The maximum PAR in all the treatments was recorded in summer months (May) and minimum in winter (January). Pruning of canopy increased the amount of PAR. Seasonal variations significantly affected the amount of PAR reaching to the understory crops. The PAR in control treatment (T_{13}) where no tree was planted was greater than the silviculture and silvipastoral treatments. Among the silviculture treatments, the *E. tereticornis* (T_3) had greater PAR than *A.nilotica* and *C.equisetifolia*. However, in silvipastoral treatments, the highest PAR was also recorded under *E. tereticornis*. This is due to less canopy cover under *E. tereticornis* as compared to *A.nilotica* and *C.equisetifolia*. PAR is well correlated to productivity of understory crops (Will *et al.,* 2005). From the data given in table 4, it is observed that the highest average PAR during three years period was recorded under treatment T_{13} where there was no tree and full sunlight was received and it was followed by *E.tereticornis*, *C.equisetifolia* and *A.nilotica* silviculture plantation but the fodder yield was significantly higher in treatment T_4, T_7 and T_{10} where *C. gayana* was planted under *A.nilotica*, *E.tereticornis* and *C.equisetifolia* respectively (Table 4). It may be due to more shade loving property of *C. gayana*. From the study, it was also observed that there was strong correlation between PAR and understory grasses (Feltrin *et al.,* 2016; Singh *et al.,* 2017)

Quality of Grass Species

The data given in table V revealed that the maximum N content in planted as well as naturally regenerated grass species was recorded in *P. purpureum* which was significantly higher ($p<0.05$) over *C. gayana*, *P. maximum* and natural grasses regenerated under treatment T_1, T_2, T_3 and in control (T_{13}). Similarly, P and K contents were also higher in *P. purpureum* and minimum with natural grasses grown in control. The highest Na^+ content (1.25%) was recorded in *C. gayana* which was significantly higher than the *P. maximum, P. purpureum,* and other natural grasses. Although, there is no direct role of light in the mineral composition of plants, but it deeply affects various biological processes (photosynthesis, transpiration, respiration, synthesis of chlorophyll, and chloroplasts), which, together, can dramatically affect the mineral composition of plants (Villa Nova *et al.,* 2007). N takes part in the composition of several molecules involved in photosynthesis and can be found in great amounts in leaves, determining their protein value. From the analysis, it was observed that the *P. purpureum* contain maximum crude protein (CP) content followed by *C. gayana* whereas, minimum in *P. maximum*. The CP content was not much affected due to tree species. However, maximum CP content was recorded in *P. purpureum* under *A.nilotica* but the difference between them due to tree species was not statistically significant (Table V). Soest, 1994 reported when the CP contents of forage crops are less than 7%, there is a reduction in their digestion due to inadequate N contents for rumen microorganisms, decreasing their population and, consequently, reducing digestibility and dry mass intake. Thus, higher CP content is necessary to meet the protein requirements of the animal organism. NDF indicates the total amount of fiber within the bulkage, which relates it to consumption. Thus, the lower the content of NDF, the higher the dry mass intake. NDF contents vary according to plant species and vegetative stage. NDF measures the entire fiber or volume component (bulkage) - hemicellulose, cellulose and lignin, being useful to estimate voluntary consumption (Rodrigues, 2010). The NDF content increased with increasing age of grasses. The average NDF content in naturally regenerated and transplanted grasses under silviculture, silvipastoral and control treatments varied from 62.3 to 73.4%. The highest NDF content was recorded in treatment T4. The *C. gayana* grown under *A.nilotica*, *C. equisetifolia, and E. tereticornis* reported significantly higher (P<0.05) NDF content over *P.maximum* and *P.purpureum* grown under the same tree species and natural grasses regenerated under silviculture and control. The NDF contents in *C. gayana, P.maximum* and *P.purpureum* grown under silvipastoral system was 7.7 to 17.8% higher over the natural grasses regenerated under silviculture and pastoral agroforestry systems. The concentration of CP and NDF increased when radiation is with high intensity and temperature and photoperiod are favorable. Our results are in conformity with the finding of Peri *et al.,* 2007. The acid detergent fiber (ADF) indicates digestibility, that is, the amount of fiber that is not digestible since it contains the highest proportion of lignin, an indigestible fraction of fiber. ADF measures the most indigestible components, cellulose and lignin (Rodrigues, 2010). The acid detergent fiber (ADF) content under silviculture, silvipastoral and pastoral systems varied from 26.53 to 41.32%. The highest ADF content (41.32%) was recorded in treatment T_{11} which was 55.7% higher over the natural grasses grown under treatment T_{13} (control). Among the grass species *P.maximum* have significantly higher ($p<0.05$) ADF content over *C. gayana* and *P. P.purpureum.*

Nutrient Uptake by Understory Grasses

Highest N.P, K and Na uptake was recorded in treatment T_4 and T_{10} which were significantly higher over rest of the treatments. This is because of higher nutrient content and dry matter yield of *C. gayana* over *P.maximum* and *P. purpureum.* Maximum Na^+ uptake was recorded with *C. gayana* whereas, minimum with *P. purpureum* because of higher Na^+ content % and yield of *C. gayana.* The highest Na^+ uptake was recorded in treatment T_4 where *C. gayana* grown under *A. nilotica* followed by treatments T_{10} and T_7. Similar trend has also been observed in *P. maximum* and *P.purpureum* (Figure 5). The Na^+ uptake in natural grasses regenerated under *A.nilotica*, *C.equisetifolia* and *E.tereticornis* and natural fallow was significantly less than the grass species grown under silvipastoral systems because of low yields of natural grasses.

Effect of Understory Grass Species on Performance of Tree Species

Plant height after planting of understory grasses increased under both silviculture and silvipastoral agroforestry systems. Maximum plant height (11.20 m) was recorded in *E.tereticornis* followed by *C.equisetifolia* and *A. nilotica*. Plant height of *E. tereticornis, C.equisetifolia* and *A.nilotica* with inter plantation of *C. gayana* was 8.3,8.5 and 5.7% higher over sole plantation and 14.6,16.4 and 20.3% higher over the initial tree height of these tree species. Highest DBH (14.12cm) was recorded in treatment T_4 which was significantly higher over treatment T_1. Similar trend was recorded in treatment T_7 and

T_{10}. The DSH of the tree species was significantly increased after plantation of under story grass species over the sole plantation of trees. The highest DSH (16.25cm) was recorded with treatment T_{10}. The crown diameter also increased after plantation of under story grasses but it was not significantly improved over the initial values. The highest crown diameter (8.75m) was recorded in treatment T_7 and the lowest (4.0m) with T_3. *A.nilotica* with *C. gayana* (T_4) silvipastoral system recorded maximum basal area (15.04 m^2 ha^{-1}) and it was followed by T_5, T_6 and T_7. Plantation of understory grasses significantly increased the lopped biomass of all the tree species over the silvicultural plantation of these species. *A.nilotica* with inter cultivation of *C. gayana* (T_4) produced maximum lopped biomass than other silvi pastoral and silviculture systems evaluated in the study. Maximum litter fall was obtained under *C. equisetifolia* in both silviculture and silvipastoral systems which was significantly higher over *A.nilotica* and *E.tereticornis* grown with the same systems (Table VI). Total tree biomass (harvested + lopped) under silviculture and silvipastoral agroforestry system varied under different treatments. The tree biomass obtained from treatment T_4 was significantly higher than treatment T_2 and T_3 however; there was no significant difference in tree biomass yield due to plantation of under story grasses.

Improvement in soil properties

Physical properties

After three years of study, the maximum reduction in soil bulk density over the initial value was recorded in treatment T_7 and the minimum in T_{13}. C.equisetifolia with inter cultivation of C. gayana (T_7) reduced 29.75% soil bulk density over the initial and 25.61% over control (T_{13}). Amongst different agroforestry systems evaluated, silvipastoral system proves more effective in terms of reducing bulk density and improving soil porosity than silviculture and control. Similarly, soil porosity under treatment T_7 increased to 38.40 and 32.23% over initial and control respectively. Water holding capacity (WHC) also increased with plantation of understory grasses over the silviculture and pastoral systems. Highest water holding capacity among silvicultural and silvipastoral systems was recorded under treatment T_1 (42.2%) and T_4 (44.3%) respectively which were significantly higher over control (T_{13}). The infiltration rate as indicated to know about the water transmission pattern within soil profile varied from 11.8-31.4 mm day^{-1}. The highest infiltration rate (31.4mm day^{-1}) was recorded under treatment T_7 and minimum with T_{13}. Infiltration rates under silvipastoral systems were than that of silvicultural systems. Silvipastoral system with plantation of *C.equisetifolia* + *C. gayana* increased infiltration rate by 166.0 and 39.80% over the treatment T_{13} and initial level of infiltration rate (Figure 6). This was due to better tree growth, improved soil bulk density, soil porosity and decomposition of grass residues. Singh *et al.,* 1989 also reported significant increase in infiltration rate under *P.juliflora* based silvipastoral system than the sole plantation of *P.juliflora*. Soil porosity, water holding capacity and infiltration rate also increased due to reduced sodicity, addition of leaf litter, and increase in microbial activities due to tree roots, better plant growth, and fine root decay (Singh *et al.,* 2004). As a consequence of increased organic matter content due to litter fall, soil porosity and water holding capacity increased significantly under silvipastoral systems over silviculture and Control.

Chemical properties

After three years of plantation of understory grasses maximum reduction in soil pH was observed in treatment T_4 and the minimum in T_{13}. This confirms earlier studies (Singh, 1995; Singh *et al.,* 2018). This resulted due to larger root surface area under treatment T_4 which enhances $CaCO_3$ dissolution in the presence of CO_2 resulting replacement of adsorbed Na+. Data given in table 7 revealed that the reduction in soil pH was more pronounced in silvipastoral systems than silviculture and control. The EC of soil significantly reduced when the trees of *A.nilotica*, *C. equisetifolia* and *E. tereticornis* were associated with *C. gayana*, *P.maximum* and *P. purpureum* (Table VII) as compare to sole cultivation of trees and natural fellow. The highest reduction in EC was recorded in treatment T_4, T_7 and T_{10} where C. gayana was cultivated under *A.nilotica, C. equisetifolia and E.tereticornis*. The highest reduction in ESP and increasing in organic carbon was recorded in treatment T_4. Decomposition of litter also leads to advancement of CO_2 which helps to mobilize the inherent Ca which hastens the reclamation process by replacing the exchangeable Na from the soil resulting reduction in soil pH and ESP (Mishra *et al.,* 2003; Solanki and Arora 2015; Singh *et al.,* 2016). The soil organic carbon content of the surface soil (0-15cm) under *A. nilotica*, *C. equisetifolia* and *E. tereticornis* silviculture system ranged from 0.24 to 0.35% however, the OC of the same tree species with understory grasses like *C. gayana*, *P. maximum* and *P. purpureum* it ranges from 0.27 to 0.41%, and under natural fallow it was 0.20%. The mean soil organic carbon content under *A. nilotica*, *C.equisetifolia,* and *E.tereticornis* with under story plantation of *C. gayana* was 0.41, 0.34, and 0.28% respectively. The soil organic carbon content in treatment T_4 increased by 17.14, 51.85 and 70.83% over treatment T_1,

T_2 and T_3 and 105% over control (T_{13}). Earlier studies conducted to monitor the ameliorative effect of different tree species on sodic soils reported that the reclamation of sodic soils depends on the quantity of organic matter added and thereby recycling of nutrients (Singh *et al.* 2014, 15, 16). Available N.P and K content under different agroforestry systems ranges from 96.2 to 150.3, 26.5 to 73.4, and 392.4 to 550.3 kg ha^{-1}respectively. Among the silvicultural systems, highest improvement in available N, P, and K contents was recorded under *C.equisetifolia*, and in silvipastoral systems maximum N, P, K content was recorded under treatment T_7. Highest Ca^{++} concentration (24.20 cmol kg^{-1}) was recorded under treatment T_7 and this rise was about 239.4% over the treatment T_{13} and 354.8% over initial. The Na content under different treatments varied from 1.14 to 1.55 cmol kg^{-1}.

Biological properties

Soil biological properties like microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), microbial biomass phosphorus (MBP) and dehydrogenase activities increased under agroforestry systems over the control. Among the silvicultural systems, highest MBC was recorded under *C. equisetifolia* followed by *A.nilotica* and *E. tereticornis*. However, in silvipastoral systems, the highest MBC was recorded in treatment T_7 (*C. equisetifolia*+ *C. gayana*) which was 3.1and 302.8% higher over treatment T_2 (*C. equisetifolia* alone) and T_{13} (control) respectively. The data given in figure 7 showed that the MBC under *C. equisetifolia* based silvipastoral system was significantly higher than the *E.tereticornis* based silvipastoral system and control but at par with *A.nilotica* based silvipastoral system. This was due to ameliorative effect of tree and grasses on soil conditions, increase in organic carbon content in the soil and higher amount of readily available organic compounds from the roots that play important role in the maintenance energy of microbial populations (Bowen and Rovira, 1991). The MBN increased significantly with the plantation of understory grasses in all the tree species over the silviculture and control treatments. The highest MBN was recorded under Acacia based silvipastoral system followed by Casuarina and Eucalyptus based silvipastoral systems. The highest improvement in this parameter was recorded under treatment T_4 which was 13.3, 25.2, 25.2, and 311.4% higher over the treatment T_1, T_2, T_3 and T_{13} respectively. The MBP also increased in silvipastoral systems than the silvicultural and control. The highest MBP (21.6 µg g^{-1}) was recorded treatment T_7 (*C. equisetifolia*+ *C. gayana*) which was significantly higher over treatment T_1, T_2, and T*3* (silviculture) and T_{10}, T_{11} and T_{12} (*E. tereticornis* + *grasses*) and the lowest inT_{13}. Dehydrogenase activity also increased significantly under silvipastoral system over the silvicultural system and control (Singh *et al.,* 2020). The highest dehydrogenase activity (6.5TPF g^{-1} h^{-1}) was recorded in treatment T_4 and the lowest (2.13 TPF g^{-1} h^{-1}) with T_{13}. The dehydrogenase activity with the plantation of *C. gayana* under *A.nilotica*, *C. equisetifolia* and *E. tereticornis* were 30.0, 22.2 and 31.5% higher over the sole plantation of *A.nilotica*, *C. equisetifolia* and *E. tereticornis* respectively. This may be due to addition of organic matter and more biological activities in the rhizosphere zone (Singh *et al.,* 2015; Solanki & Arora, 2015). Ogunwole *et al.,* (2007) also reported that the microbial biomass increased under canopy due to more biological activities in the rhizosphere zone, which increased microbial biomass carbon. Nutrient availability to the plants also controlled by the microbial activities in the soil (Holmes and Zak, 1994).

Relationship between chemical and biological properties

The pH and EC were significantly correlated with ESP and Na^{+} content however, there was negative correlation of these parameters with OC, available N,P,K , soluble cations (Na^{+}, Ca^{++}) and microbial properties. Significant correlation was found between ESP and Na^{+} content. The organic carbon has significant correlation with available N, P, K, Ca^{++}, and MBC, MBN, MBP and dehydrogenase activity. Similarly, available N, P, K, has positive correlation with available P, K, Ca^{++} and microbial activity in the soil. In contrast, there was a negative correlation between Na^{+}, Ca^{++} and microbial activity whereas; Ca^{++} has significant correlation with microbial activity in soil. The MBC, MBP, and MBN have significant correlation between each other (Table 8) Ca^{++}, MBC, MBN, MBP and dehydrogenase activities however, it was negative with Na^{+}.

CONCLUSIONS

The tree growth and biomass significantly increased with plantation of understory grass species. The *C. gayana*, a perennial fodder grass found highly tolerant to sodicity and shade loving grass species for plantation under 10 year old tree species like *A.nilotica*, *C. equisetifolia* and *E. tereticornis* multipurpose tree species suitable for sodic soils. Among the grass species tested under the study, *C. gayana* found highly suitable in terms of its biomass yield and nutritive value. The results indicated a positive association between photosynthetically active radiation and dry matter production of grass species. Besides, photosynthetically active radiation indirectly affects crude protein and forage neutral detergent fiber. Plantation of grass species under the trees strongly influenced the soil physico-chemical and biological properties because of increasing organic carbon status in the soil. Soil microbial biomass activity which regulated by the root carbon input and litter fall were also higher under silvipastoral systems relative to the silviculture systems. Higher Na^+ uptake was recorded in *A.nilotica* + *C. gayana* silvipastoral system whereas, minimum with *C. equisetifolia*+ *P. purpureum.* From the study, it is concluded that plantation of *C. gayana* grass species under *A.nilotica* silvipastoral system could be a viable alternate land use system for restoration of degraded sodic soils.

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REFERENCES

Abrol IP, Yadav JSP, Massoud FI. 1988 Salt-affected soils and their management. FAO Soils Bulletin 39, Food and Agriculture Organization of the United Nations, Rome, Italy, 131 pp.

Abraham EM, Kyriazopoulos AP, Parissi ZM, Kostopoulou P, Karatassiou M, Anjalanidou K, Katsouta C. 2014. Growth, dry matter production, phenotypic plasticity and nutritive value of three natural populations of *Dactylis glomerata* L. under various shading treatments. *Agroforestry Systems* 88: 287-299.

Ahmad P, Latef AAH, Rasool S, Akram NA, Ashraf M, Gucel S. 2016. Role of Proteomics in Crop Stress Tolerance. *Frontier of Plant Science* https://doi.org/10.3389/fpls.2016.01336.

Akmal M, Hameed-ur-Rehman, Farhatuallah M. Asim, Akbar H. 2010. Response of maize varieties to nitrogen application for leaf area profile, crop growth and yield components. *Pakistan Journal of Botany* **42**(3): 1941-1947.

AOAC 2007. Official Methods of Analysis of AOAC International. 18th Edn., Revision 2. Association of Official Analytical Chemists, USA., pp: 232.

Ates E. 2016. Determining drought tolerance of new fodder pea and Persian clover genotypes at the germination and early seedling stages. *Fresenius Environmental Bulletin* **25**: 6020-6029.

Brady NC. 1990. *The nature and Properties of Soils*. New York: Macmillan Publishers.

Bowen GD, Rovira AD. 1991. The rhizosphere. The hidden half of the hidden half. In: Waisel Y, Eshel A and Kafkafi U (eds) Plant Roots: The Hidden Half (pp 641–669). Marcel Dekker, New York, USA.

Casida L, Klein D, Santoro T. 1964. Soil dehydrogenase activity. *Soil Science* 98: 371-376.

Difante G S, Nascimento Junior D, Silva SC, Euclides V P B, Montagner D B, Silveira M C T. 2011. Características morfogênicas e estruturais do capim-marandu submetido a combinações de alturas e intervalos de corte. *Revista Brasileira de Zootecnia* **40**(5): 955-963. https://doi.org/10.1590/S1516-35982 011000500003.

El-Mowellhey N. 1998. Sustainable management of salt-affected soils in the arid ecosystem. Cairo, Egypt, 21-26 September 1997. p 1-2.

FAO, 2016. Salt-affected soil. http://www.fao.org/soils-portal/soil-management/ management- of-some-problem-soils/salt-affected-soils/more information- on-salt-affected-soils/en/ August, 2016.

Fatehnia M K, Tawfiq K, Ye M. 2016. Estimation of saturated hydraulic conductivity from double ring infiltrometer measurements. European Journal of Soil Science. https://doi.org/10.1111/ejss.12322.

Feltrin RP, Will RE, Meek CR, Masters RE, Waymire J, Winson DS. 2016. Relationship between photosynthetically active radiation and understory productivity across a forest –Savanna continuum. Forest ecology and Management **374**: 51-60.

Gobbi KF, Garcia R, Garcez Neto AF. 2009. Características morfológicas, estruturais e produtividade do capim braquiária e do amendoim forrageiro submetidos ao sombreamento. *Revista Brasileira de Zootecnia* **38** (9):1645-1654.

Gupta SR, Sinha A, Rana RS. 1990. Biomass dynamics and nutrient cycling in a sodic grassland. *International Journal of Ecology and Environmental Science* **16**: 57–70.

Holmes EW, Zak DR. 1994. Soil microbial biomass dynamics and net nitrogen mineralization in northern hardwood ecosystems. *Soil Science Society of American Journal* **58**: 238-243.

Jackson ML. 1967. Pp. 183-226 in Soil Chemical Analysis. Prentice Hall of India, New Delhi.

Kaur B, Gupta SR, Singh G. 2002. Bioamelioration of a sodic soil by silvipastoral systems in northwestern India. *Agroforestry Systems* **54**: 13–20, 2002.

Kumar A. 1996. Use of *Leptochloa fusca* for the improvement of salt affected soils. *Experimental Agriculture* **32**: 243−149.

Mandal AK, Sharma RC, and Singh G. 2009. Assessment of salt affected soils in India using GIS. *Geocarto International* **24** (6): 437-456.

Mishra A, Sharma SD, Gupta MK. 2003. Soil rehabilitation through afforestation: Evaluation of the performance of P. juliflora, Dalbergia sissoo and E.tereticornis plantations in a sodic environment. *Arid Land Research and Management* **17**(3):257–269.

Ogunwole JO, Patolia JS, Chaudhary DR, Ghosh A, Chikara J. 2007. Improvement of the quality of a degraded entisol with *Jatropha curcas* L. under Indian semi-arid conditions. Expert seminar on *Jatropha curcas* L. Agronomy and Genetics, March 2007:26–8 [Wageningen, the Netherlands, Published by FACT Foundation].

Olsen SR, Dean LA. 1965. Phosphorus, In C.A. Black, ed., *Methods of soil analysis*. Part 2. *American Society of Agronomy*, Madison, Wisconsin, USA. pp, 1035-1049.

Peri PL, Lucas RJ, Moot DJ. 2007. Dry matter production, morphology and nutritive value of *Dactylis glomerata* growing under different light regimes. *Agroforestry Systems* **70**:163-79.

Qadir M, Quillerou E, Nangia V, Murtaza G, Singh M, Thomas RJ, Drechsel P, Noble AD. 2014. Economics of salt-induced land degradation and restoration. *Natural Resources Forum* **38**(4):282–295.

Rao DLN, Ghai SK.1985. Urease and dehydrogenase activity of alkali and reclaimed soils. *Australian Journal of Soil Research* **23**:661–665.

Rao DLN, Pathak H. 1996. Ameliorative influence of organic matter on biological activity of salt – affected soils. *Arid Soil Research and Rehabilitation* **10**: 311–319.

Richards LA (Ed.). 1954. Diagnosis and Improvement of Saline and Alkali Soils. Handbook, No. 60. U.S. Department of Agriculture. Oxford & IBH Publication Co., New Delhi. 129 pp.

Rodrigues RC. 2010. Métodos de análises bromatológicas de alimentos: Métodos físicos, químicos e bromatológicos. Pelotas: Embrapa Clima Temperado, 177p. Documentos, 306.

Sharma DK, Chaudhary SK, Singh A. 2014. In salt affected soils: agroforestry is a promising option. *Indian farming* **63** (11): 19-22.

Shetty BV, Singh V. 1993. Flora of Rajasthan, Vol. I–III. Botanical survey of India, Howrah, India.

Singh G, Abrol I P, Cheema SS. 1989. Effect of gypsum application on mesquite (P. juliflora) and soil properties in an abandoned sodic soil. *Forest Ecology and Management* 29:1–14.

Singh B, Garg VK, Singh PK, Tripathi KP. 2004. Diversity and productivity effect on the amelioration of afforested sodic soils. *Indian Forester* **130**:14-26.

Singh JS, Raghubanshi AS, Singh RS, Srivastava SC.1989. Microbial biomass acts as a source of plant nutrients in dry tropical forest and savanna. *Nature* **338**:449–500.

Singh G. 1995. An agroforestry practice for the development of salt lands using *Prosopis juliflora* and *Leptochloa fusca*. Agroforestry systems **29**: 61–75.

Singh G. 2009. Salinity-related desertification and management strategies: Indian experience. *Land Degradation and Development.* **20**: 367−385.

Singh YP, Singh G, Sharma DK. 2010. Biomass and bio-energy production of ten multipurpose tree species planted in sodic soils of Indo-Gangetic plains. *Journal of Forestry Research* **21**(1): 19-24.

Singh YP, Singh G, Sharma DK. 2011. Ameliorative effect of multipurpose tree species grown on sodic soils of Indo-Gangetic alluvial plains of India. *Arid Land Research and Management* **25**: 55-74.

Singh YP, Singh G, Sharma D.K. 2014. Bio-amelioration of alkali soils through agroforestry systems in central Indo-Gangetic plains of India. *Journal of Forestry Research* **25** (4): 887−896. DOI 10.1007/s11676-014-0535-1.

Singh YP, Nayak AK, Sharma DK, Singh G, Mishra VK, Singh D. 2015. Evaluation of *Jatropha curcas* genotypes for rehabilitation of degraded sodic lands. *Land Degradation and Development* **26**:510-520.

Singh YP, Mishra VK, Sharma DK, Singh G. Arora S. Dixit H, Cerda A. 2016. Harnessing productivity potential and rehabilitation of degraded sodic lands through Jatropha based intercropping systems. *Agriculture, Ecosystems and Environment* **233**: 121-129.

Singh YP, Singh G. Sharma DK, Arora S. 2017. Evaluation of different agro-forestry systems for their effect on alkali soils. *Journal of the Indian Society of Soil Science* **65**(1): 42-47.

Singh YP, Singh G, Mishra VK, Arora S. 2018. Evaluating multipurpose tree species for biomass production and amelioration of sodic soil. *Journal of the Indian Society of Soil Science* **66**(4): 399-405.

Singh YP, Singh G, Mishra VK, Arora S, Singh B, Gupta RK. 2018. Evaluation of multipurpose tree species for managing degraded sodic land ecosystem in Indo-Gangetic alluvial plains**.** *Tropical Ecology* **59**(4): 701–714.

Solanki R, Arora S. 2015. Leaf litter dynamics in agroforestry system affecting microbial activity in saline soils. *Journal of Soil and Water Conservation* **14**(4): 332-339.

Soest PJ van.1994. Nutritional ecology of the ruminant. 2.ed. New York: Cornell University, 476p.

Subbiah BV, Asija GL. 1956. A rapid procedure for estimation of available nitrogen in soils. *Current Science* **25**: 259-263.

Vance ED, Brookes PC, Jenkinson DS. 1987. An extraction method for measuring soil microbial biomass carbon. *Soil Biology and Biochemistry* **19**:703-707.

Villa Nova Na; Tonato F, Pedreira CGS. 2007. Método alternativo para cálculo da temperatura base de gramíneas forrageiras. *Ciência Rural* **37**(2): 545-549.

Wang X J, Methurst P J, Herbert A M. 1996. Relationships between three measures of organic carbon in soils of eucalyptus plantation in Tasmania. *Australian Journal of Soil Research* **34:** 545–53.

Wilde S A, Voigt GK, Iyer JG. 1964. Soil and plant analysis for tree culture. Oxford Publishing House, Calcutta.

Will RE, Narahari NV, Shiver BD, Teskey RO. 2005. Effects of planting density on canopy dynamics and stem growth for intensively managed loblolly pine stands. *Forest Ecology and Management* **205**: 29–41.