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Productivity of alley farming with the help of *Leucaena leucocephala* (ipil ipil) and *Penniseteum purpurium* (napier grass) in rain-fed condition of Potohar, Pakistan

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Abstract

The aim of this study is to assess good quality forage, firewood and carbon stock on sustainable basis by agro-forestry intervention with the help of alley cropping on rain fed areas, and to improve the livelihood of the poor farmer at their door steps. The agro-forestry is one of the promising techniques to overcome food shortage problem and to provide the forage, fire and fuel wood supply on sustainable basis to the resilient farmer Rahman *et al.* (2016). The introduction of alley farming in agro-forestry enhance the biomass productivity, improve soil health, have more ability of conserving water and create balance in atmosphere Baig *et al.* (2013). The livestock mainly depends on the natural pasture lands not only in the Potohar region but all around Pakistan. The livestock are greatly suffered from insufficient and less nutritive feed during the dry summer and winter months. Therefore, the introduction of alley cropping practice in agro-forestry leguminous trees with nutritious grass species is the only solution for sustainable supply of good quality forages to improve the livelihood of the resilient farmers for their livestock at their door steps. Alley cropping experiment was conducted in the rain-fed area of Range land Research Institute (RRI), National Agricultural Research Centre (NARC), Islamabad. *L. leucocephala* (iple iple) plant *and Pennisteum purpureum* (Elephant grass) grass were selected for this study. There were three treatments and three replications in this research study. An area of one ha was selected and divided into four equal parts. There were four lines (contour) of plants and three plots were allocated for grasses. On the contour lines *L. leucocephala (iple iple) plants* were planted at one foot apart from each other. Space between two contour linesi.e called alley, the grass tufts on (1×1) feet was planted and alley to alley distance was retained to twenty feet. Biomass production for grasses, fodder (leaves), firewoods and their carbon stock were determined after every three month's interval. Soil samples were collected at the four different depths (0-20, 20-40, 40-60, 60-80 cm) for soil in-organic carbon determination. The study was conducted in Completely Randomized Block Design (CRBD) under field conditions without irrigation and fertilizer. The result indicated that maximum biomass production (kg/ha) of grasses and plants were higher during May-August (Grass: 5.10 kg/ha, Tree: Leaves: 4.8 kg/ha, and fire wood: 5.7 tons/ha). The amount of carbon in grass dry weight was also maximum during May-August, i.e. 0.65 (Mg C ha^{-1}).Similarly, in *Leucaena leucocephala* (iple iple) leaves and firewood showed that dry weight of leaves contained maximum carbon in May-August 0.57 (Mg C ha^{-1}) and high carbon content in firewood during September-October 0.85 (Mg C ha^{-1}). The data for soil in-organic content showed that as their depth increases from surface i.e. 0 to 80 cm the soil in-organic content also increases gradually with the depth. The soil organic contents were only significant at the depth of 0-20 cm 2.10 (Mg C ha^{-1}) and gradually decreasing as the depth increases from 20 to 80 cm. This study showed maximum biomass production of grasses and trees which can improve the cattle production, firewood/timber shortage issues and significant role of trees in mitigating rampant climate change issues It can recover the soil fertility status regarding nitrogen simultaneously, it will provide forage in smallholder farming systems.

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Introduction

The rapidly growing population, development, degradation of land and the change in climate are the chief causes for the food deficiency in the developing countries. The use of woody trees in agro-forestry is one of the promising techniques to resolve these issues and overcome food shortage problem Rahman *et al.* (2016*)*. The agro- forestry creates tree crop combination system on the arable areas. This type of system remedy land degradation, improve biomass production as well as enhance soil productivity by interaction with various component such as trees, crops/grasses, soil and cattle's Kumar (2006). The alley cropping technology is a type of agro-forestry system which means to plant suitable grasses, trees or shrubs or mixed them in appropriate intervals along the contour as hedgerows on slopping lands as well as on the command areas. The hedgerow plants act as barrier for runoff, decrease erosion, slow declining slopes, formatting terraces at last for sustainable use of the sloping farmland Dixin *et al.* (2002).The success of integrated alley cropping system depends on the introduction of leguminous trees kang *et al.* (1999). The function of leguminous shrubs or trees is to provide nitrogen (N), organic compounds (OM) and to recover the trickled nutrients (e.g. P, K) to crops for the better yield Yamoah *et al.* (1986). The leguminous plant are mostly trimmed then used for fodder for the livestock, staking and as the firewood. The major challenge to animal production in tropics is not only the seasonal variation in fodder yield but also value of grasses. It is generally suitable forage of better nutritive value in the rain season but in case of dry and in winter seasons accessible fodder from the natural pastures is insufficient equally in quality as well as quantity to provide even the maintenance necessities of livestock. *Leucaena leucocephala,*not only provide good quality/quantity forage, it can also provide timber, firewood, shade, green manure, and control of erosion. Therefore*,* this study was conducted to do assessment of good quality grass forage, fire/fuel wood and fodder from tree leaves on the sustainable basis round the year on farm lands from agro-forestry practices to improve the livelihood resilient farmer. Sequester carbon in soil, from the plant and grass biomass will also be estimate to minimize the carbon level in atmosphere by agro-forestry intervention.

Materials and methods

Experimental area

The study of Integrated farming system alley cropping experiment was conducted in the field area of Rangeland Research Institute (RRI), National Agriculture Research Center (NARC), and Islamabad. Islamabad is situated on 33.43° N and 73.04° E on the edge of Pothwar plateau at the end of Margalla Hills in the Federal Islamabad Capital Territory and altitude is 507 meters. It lies in the moist, hot subtropical climate and humid summers, monsoon season followed by cool winter. The soil is locally outwash/loessic, alluvial in the source. It is mildly calcareous and content of lime is equally dispersed in complete contour of soil. Soil in this region are not sodic or saline which has little basic pH with minor amount of inorganic substances. It contains less organic material that ensures 7.5-8.5 pH. Rain fall is quite irregular which differs significantly from 250 mm in south-west to 1000 mm in the north-east areas. During the summer months more than 70% of annual rain falls occur.

Experimental design

An area of one ha was selected and was divided into three equal compartments. A-frame was used for making the contour lines at the same altitude on one ha. On the contour lines the sapling of *Leucaena leucocephala* was planted one foot apart. In between the two contour lines called alley, the grass tuft on (1x1) feet was planted and alley to alley distance was retained twenty feet's. *Leucaena leucocephala* with Napier grass was planted in rain fed condition. There were three treatments and three replications. A transect line was drawn on the contour line and after five feet interval five quadrates were taken for biomass production and for fire wood. Each quadrate was at a distance of five meters apart. Similarly, in each alley three quadrates for bio-mass production with quadrate methodology with one meter, two and three meters apart from the cropping of ipile ipile was recorded in three growing seasons (Winter, Monsoon and Spring). After each growing season all the plants were cut down at the height of three feet. Green fodder and fire wood were removed for kg/ha and also for above carbon phytomass. In one meter quadrate the soil up to one meter depth was dug out for inorganic, organic carbon. The study was conducted in Completely Randomized Block Design under field conditions without irrigation and fertilizer.

Sample collection

The following parameters regarding field experiment were determined.

Above and below grass biomass with carbon

The vegetation (grasses) present within each quadrant was harvested at ground level for calculation of above ground grass biomass and also for carbon stock. We calculated the fresh biomass data immediately after harvesting and then dried these samples at 60 ^{o}C in an oven till constant weight was achieved. The below ground root samples were taken by digging the ground at appropriate root depth of 1 m within the 1m^2 quadrant. The roots were washed and after drying sieved to remove soil and stones. The data for fresh and dry grass samples were recorded and 0.50 was applied co-efficient for the conversion of biomass data into Carbon stock.

Plants Green fodder and fire wood

Plants were cut down at height of one meter. Their green and fire wood were separated for biomass kg/ha and carbon Mg C/ha.

Lab experiment

The lab/chemical experiments were carried out in Land Resources Research Institute labs, NARC, Islamabad.

Phytomass organic carbon

The green Phyto mass after overnight oven drying at 60°C were meshed finely and put in oven dried clean crucibles. Samples weight was recorded and then placed in Thermolyne for 24 hours. The ashes of these samples were weighed for organic carbon content measurements.

Soil inorganic Carbon ($CaCO_3$)

The Colorimetric method was employed to calculate soil inorganic carbon. The soil samples were meshed finely and then screened through size of 2 mm.

The total amount of Carbonates present within 100g of dry soil is known as the % Calcium Carbonate $CaCO_3$ (%). The total Carbonates i.e. $CaCO_3$ and $MgCO_3$etc are expressed in the form of $CaCO_3$.The volumetric analysis was used to determine percentage of $CaCO_3$ which is actually based on the liberation of the carbon dioxide CO_2 during Hydrochloric acid solution HCl_4 N application in soil samples.

The soil organic matter (SOM)

The wet oxidation method was used to calculate amount of carbon in soil samples. The soil samples were oxidized using potassium dichromate in presence of sulphuric acid. In this reaction carbon was oxidized and dichromate was reduced whereas, CO_2 was liberated.

The difference between potassium dichromate used and left after reaction gave amount of oxygen consumed in reaction which was determined using titration method. In titration method 0.5 N Ferrous Ammonium Sulphate or Ferrous Sulphate solution was used and diphenylamine was used as indicator.

The proximate analysis

The proximate analysis of grass and tree samples were done in Animal Nutrition Lab, NARC, Islamabad by using methods mentioned in AOAC, 2000.

Results and discussion

Productivity of Pennisetem purpureum (napier grass)

It was found that the green biomass production was higher during Monsoon (1.70 tons/ha) followed by spring (1.56 tons/ha) and least biomass was obtained during winter (1.23 tons/ha) (Table 1).

Table 1. Production of the *Leucaena leucocephala* (ipil ipil) tree and *Pennisetum purpureum* (napier grass) grass.

Sr.No.	Seasons	Grass green weight (*t/ha)Pennisetum purpureum*	Green weight (*t/ha)* of ipil ipil leaves cut from 1m height	Green weight *(t/ha)* of ipil ipil fire wood timber cut from 1m height
01.	Spring	1.5667^{ba}	1.3667^{b}	0.9000^{c}
02.	Monsoon	1.7000^{a}	1.6000^{a}	1.2000^{b}
03.	Winter	1.2333^{b}	0.9000	1.7000^{a}
	LSD 0.05	0.2343	0.1439	0.2172

The high soil water content in soil leads to high productivity in grasses and trees. According to Dubeux *et al.* (2017) the alley farming system appeared to be using excess amount of water as compared to conventional annual cropping systems. Conversely, the trees may have positive impact that it improves grass growth by promoting favorable physical and geochemical conditions. In this condition trees increase soil water content linked to the hydraulic lift or it may occur by decreasing the effect of solar radiation, reducing evapotranspiration of the sub canopy and the temperature of soil along with water stress issues related to italic herbaceous plants Ludwig *et al.* (2004[a, b]). Such type of system improves the availability of nutrients because of the trees litter inputs. The high nutrients accessibility can develop the better quality of fodder of the sub canopy grasses therefore appealing the grazer Treydte *et al.* (2007),(2008)*;* Ludwig *et al.* (2014).

Table 2. Carbon Stock (Mg C ha^{-1}) in *Pennisetum purpureum* (napier grass)*, Leucaena leucocephala*(ipil ipil) leaves and firewood on dry basis in three seasons.

Sr. no.	Seasons	Carbon in *Pennisetum purpureum*	Carbon in *Leucaena leucocephala* leaves	Carbon *in Leucaena leucocephala* fire wood timber
01.	Spring	0.56665^{b}	0.36835^{b}	0.45^{c}
02.	Monsoon	0.65^{a}	0.56665^{a}	0.61665^{b}
03.	Winter	0.36665^{c}	0.26665^{c}	0.8500^{a}

The mean values with unalike superscripts vary significantly ($P < 0.05$).

In temperate areas the deeply rooted trees take more advantage from only access to the winter precipitation which had infiltrated below root zones of grasses. The Thorvaldsson *et al.* (2005) studies revealed that maximum growth rate normally occurs on the relative warm and sunny days in the period having frequent rainfall. The excess of rain could be required for the rapid grass growth. The fascinating reasons for increase in the primary productivity or reduction of nitrogen fertilizer inputs and the greater Carbon sequestration (above and below ground) when introducing a N_2 fixing tree legume in the grassland system.

Productivity of Leucaena leucocephala*(ipil ipil)*

The data for *Leucaena leucocephala* green leaves biomass showed that production was higher during monsoon, (1.60 tons/ha) followed by spring (1.36 tons/ha) and least biomass was obtained during winter (0.90 tons/ha).On the other hand timber production in three seasons showed that production was high during winter (1.70 tons/ha) followed by monsoon (1.20 tons/ha) and least biomass was obtained during spring, (0.90 tons/ha) (Table 1).

The trees showed maximum growth due to soil water content during monsoon rainfall summer which reduce growth rates. The studies of Chaves *et al.* (2002) stated that reason of trees resistance against the harsh condition such as drought is accredited to the widespread roots system that explore maximum soil for water and to the efficient tolerance towards stress. Similar findings of Anderson *et al.* (2009), Udawatta *et al.*(2002), Verchot *et al.* (2007) about agro-forestry practices revealed that highly porous soil decrease the rate of runoff and intensify soil cover that improves water level in soil profile by increasing rate of infiltration as well as retention and especially decreases moisture stress in the years of minimum rainfall. Jose *et al.* (2012) stated that agro-forestry has capability to conserve biodiversity through support of agricultural production and can show resilience towards the change in climate. The agro-forestry system consisting varieties of trees that have tolerance and resilience than most of the crop plants although provide protection but these trees are not resistant to most of the hostile effects of change in climate Schoeneberger M *et al.* (2012).

Table 3. The soils inorganic Carbon (SIC %), and soils organic carbon (SOC %) (Mg C/ha).

Depths (cm)	SIC (%)	SOC (%)	TC (Mg C ha^{-1}
0-20	1.33^{dc}	0.77^{a}	2.10
20-40	1.37^{c}	0.43^{b}	1.80
40-60	1.45^{ba}	0.36^{bc}	1.81
60-80	1.51^{a}	0.29^{d}	1.80

Soil inorganic carbon (SIC %).

Carbon stock in above ground dry grass

It was found that amount of carbon in grass dry weight was also maximum during monsoon (0.65 Mg C/ha) followed by spring (0.56 Mg C /ha) and in winter (0.36 Mg C/ha) (Table 2). The value for carbon stock in *Pennisetum purpureum* was significant which shows its remedial potential for carbon sequestration from environment. According to Dubeux *et al.* (2017) there is more potential to enhance C sequestration under the tree legume grass mixtures as compared with grass in monocultures. The amount of carbon sequestrated from topmost soil (20 centimeters) is normally less (25 M C/ha) than in above ground crops cover. Tree legumes establishment is related to the no-till practice which increase carbon stock in top soil between 0.5 to 1.6 M C/ha year with the values above ones detected for the annual cropping systems. Mutuo *et al.* (2005) reported that the average above ground C stocks up to the 60 M C/ha depends on land used system rotation age. According to Marin (2016) studies plants carbon stock directly depends on the plants biomass quantity. The maximum biomass leads to maximum carbon stock. Cardinael *et al.* (2015) stated that agroforestry systems such as agro ecosystems combine shrubs or the trees with agriculture system are important because this system enhance production of biomass as well as the carbon storage in soil whereas, maintain agronomic productivity very well. It was recommended that herbaceous vegetation sown between rows of trees essentially increase storage of carbon.

Carbon stock in dry fodder and fire wood timber

The analysis of *Leucaena leucocephala* leaves and firewood timber cut from 1 m height showed quite similar variation in carbon content. The dry weights of leaves contained maximum carbon in monsoon, (0.56 Mg C/ha) followed by spring (0.36 Mg C/ha) and least during winter (0.26 Mg C/ha). The dry weight (t/ha) of *Leucaena leucocephala* fire wood timber cut from 1m height indicated higher carbon content in fir wood during winter (0.85 Mg C/ha) followed by monsoon (0.61 Mg C/ha) and very less in spring (0.45 Mg C/ha) (Table 2) respectively. The studies of Cardinael *et al.* (2016) showed that trees have the ability to store carbon in both above and below ground biomass and trees can also increase stock of organic carbon in soil through it organic inputs. The trees in specific rows increase organic carbon in soil by enhancing 50 percent of extra storage of organic carbon in plot scale of silvo-arable although it consist small surface area. Cardinael *et al.* (2016) stated that agriculture system represents competence to boost organic carbon in soil underneath 30 centimeters and storage of C in woody products. Aalde *et al.* (2006) studies revealed that trees afford greater above as well as below ground biomass as compared to herbaceous vegetation and it's almost 50% of the dry mass is totally Carbon. Furthermore, trees intensify the total fine roots production; the rhizo deposition and the litter fall all promote organic C sequestration in soil Montagnini& Nair (2004), Nair *et al.* (2009). The intercropping scheme will improve the total storage of organic carbon in the ecosystem and correspondingly help to lessen releases of the greenhouse gas emissions such as methane (CH_4) and the nitrous oxide (N_2O) from the soils Dougherty *et al.* (2009), Evers *et al.* (2010), Bergeron *et al.* (2011), Amadi *et al.* (2016), Baah-Acheamfour *et al.* (2016), Kim *et al.* (2016). The perennial woody vegetation addition into crops/grass systems is important due to its contribution of C storage in vegetation especially through increased of soil C through litter fall and the root exudates. Agro-forestry system has potential to enhance soil organic carbon(SOC) because the shrubs and the crops underneath shrubs or trees in agriculture system change both the above as well as below ground productivity of the agro-ecosystems, by modifying roots depth and root distribution. This system increases the amount of litter fall that results in change of environmental conditions of the land Jose (2009). The increment of organic stock can encourage various natural phenomena that results in the SOC accretion for instance aggregation of soil, humiliation and transport of carbon in the lower layers of soil through deeply rooted plants Nair (2011) while the deeply rooted trees allow more C to be stored in deeper.

The data for soil inorganic carbon (SIC) content is significantly higher as illustrated in (Table 6), which shows that as the depth increases from surface i.e. 0 to 80 cm the soil inorganic carbon content also increases gradually with the depth. The highest SIC percentage (1.51 %) is found at the depth of 60 cm to 80 cm which is significantly higher but not too much than SIC percentage (1.45 %) at 40 cm to 60 cm. The SIC percentage (1.37 %) is also significant at the depth of 20-40 cm followed by SIC percentage (1.33 %) at deepness of 0-20 cm from top surface which is least than all but quite significant in percentage amount.

Soil organic carbon (SOC %)

The soil organic carbon contents are clear from (Table 6), which shows that the amount of SOC is only significant at the depth of 0-20 cm and below than this SOC go on decreasing/insignificant as the depth increases from surface 20 to 80 cm. The highest SOC (0.77 %) i.e. 2.10 Mg C ha is found less deep excavated soil of 0-20 centimeters which is significantly higher than the SOC at all other depth. The SOC at the depth of 20-40 cm is (0.43%) 1.80 Mg ha^{-1} carbon near the significant followed by less significant SOC (0.36 %) 1.81 Mg C /ha base of 40-60 centimeters and the least SOC (0.29 %)1.80 Mg C/ha at the deepness of 60-80 centimeter (Table 6). Soil play vital role in the global budget of carbon as it represents 2-3 time the pool of total carbon in atmosphere. It has been explored that since the years 1850's, the discount of organic matter in agriculture lands has donated almost 70 Gt atmospheric carbons. According to predictable values around 70% French agricultural top soils are not saturated in the organic carbon therefore it has additional ability for the storage of organic matters Angers *et al.* (2011). The soil act as significant pool of C due to its C storage in above as well as below-ground biomass which is vulnerable to loss by fire or the other surface disturbances whereas, soil C can be more stable as well as long-term C storage is provided where it is not disturbed by tillage or any other processes Laganiere *et al.* (2013), Baah-Acheamfour *et al.* (2014), (2015). In agro-forestry arrangements i.e. in agro ecosystem correlating shrubs/trees with the crop plants are identified as a likely land use to sustain or intensify SOC stock. Several existing studies only account the surface layers of soil while, agro-forestry consist of very deep-rooted trees Mulia &Dupraz (2006) therefor, could influence deep organic carbon stock in soil.

Conclusion

It was concluded that the alley cropping is one of the effective agro-forestry technique which can give multiple products at the same field and growth season than the monoculture systems. This study showed maximum biomass production of grasses and trees which can improve the cattle production, firewood/timber shortage issues and most important trees can play significant role in climate change. The maximum carbon in grass and in *L. leucocephala* leaves and firewood shows their significant role in carbon sequestration.

The following suggestions can help to promote alley cropping production:

It can recover the soil fertility status with regard to nitrogen while at the same time it will provide forage in smallholder farming systems.

The farmer may propose to select suitable leguminous tree/shrub for particular crops/grass production.

The alley cropping proposed to be implemented in area where remediation of severe soil and water losses is required.

Exotic species proposed to be well tested in lab before locally used. Indigenous trees give preference rather than exotic species.

Government may aware local farmers about the multiple benefits by seminars launching awareness programs, etc.

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