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Carbon sequestration potential of pea-oat intercropping system in rice fallows as influenced by integrated nutrient management

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Abstract
A field experiment was conducted at Assam Agricultural University, Jorhat in 2014-15 and 2015-16 to study the "Carbon sequestration potential of pea-oat intercropping system as influenced by integrated nutrient management". The Carbon sequestration potential (CSP) was influence statistically by cropping system in both the years. The highest carbon sequestration potential was observed in sole pea cropping in all the years of experimentation. Among the intercropping system the highest Carbon sequestration potential of 1.14 and 1.26 Mg/ha in 0-15 cm and 0.90 and 1.08 Mg/ha in 15-30 cm was recorded from 3:3 row proportions during 2014-15 and 2015-16, respectively. Application of nutrients at different treatment combinations of 50% N through Recommended Dose of Fertilizer + 50% N through vermicompost gave the highest Carbon sequestration potential of 1.54 and 1.60 Mg/ha in 0-15 cm and 1.29 and 1.55 Mg/ha in 15-30 cm during 2014-15 and 2015-16, respectively. It can be concluded that a planting geometry of 3:3 row proportion with integrated nutrient management of the soil with 50% N through vermicompost + 50% N through inorganics recorded significantly better bulk density, soil organic carbon content, microbial biomass carbon and carbon sequestration potential in all the experimental years.

Keywords: carbon sequestration, intercropping system, pea-oat, integrated nutrient management, FYM, vermicompost

Introduction
Carbon sequestration in agricultural soils is frequently promoted as a practical solution to slow down the rate of increase of CO_2 in the atmosphere. Carbon sequestration is defined as the process of capture and long-term storage of atmospheric carbon dioxide (CO_2) and may refer specifically to the process of removing carbon from the atmosphere and depositing it in a reservoir. When carried out deliberately, this may also be referred to as carbon dioxide removal, which is a form of geoengineering. Soil is the largest reservoir of terrestrial carbon (C), storing approximately 53% of the terrestrial carbon. Approximately 10% of the CO_2 in the atmosphere is cycled through the soil each year. Generally, plant biomass (above and below ground residues) is the primary source of carbon input into SOC. When biomass decomposes, it is incorporated into SOC, of which up to 70-80% is defined as humic substance. Once it is becomes part of SOC, carbon is stored in soil for a long time since humic substasnces are recalcitrant. The 89% of global potential for agricultural greenhouse gas mitigation would be through carbon sequestration (Smith et al., 2008). Thus, large quantities of carbon from the atmosphere would be removed and agricultural activity can contribute substantially to cutting greenhouse gas emissions. Information on organic C stocks in agricultural soils is important because of the effects of SOC on climate change and on crop production. The SOC stock at any time reflects the long-term balance between additions of organic C from different sources and its losses through different pathways. Following the adoption of large-scale intensive cropping, this long-term balance would modify since intensive cropping encourages oxidative losses of C due to continued soil disturbance, while it also leads to a large-scale addition of C to the soil through crop residues (Majumder *et al*., 2008) [8]. This may cause either a net buildup or a net depletion of SOC stock (Kong *et al*., 2005) [4]. Cropping systems and management practices that ensure return of the greater amount of crop residue to the soil are expected to cause a net buildup of the SOC stock. The SOC pool in soils of India is 2.2% of the world pool for 1 m depth and 2.6% for 2 m depth. Potential of soil C sequestration in India is estimated 6 to 7 Tg C/year for adoption of recommended management practices on agricultural soils, and 22 to 26 Tg C/year for secondary carbonates, while total potential of soil C sequestration is 39 to 49 (44±5) Tg C/year (Lal, 2004) [5, 6]. The SOC stock at any time reflects the long-term balance between additions of organic C from different sources and its losses through different pathways. A good farming practice can decrease CO_2 evolution from soil into the atmosphere and enhance soil fertility and thus productivity increased (Lal, 2004) [5, 6].

Integrated nutrient management helps maintain soil fertility and improve plant nutrient supply at an optimum level for sustaining the desired productivity through optimization of the benefits from all possible sources on a long-term basis. Application of N, P and K either through inorganic fertilizers or through combination with organics such as farmyard manure (FYM) or crop residue or green manure improves the SOC concentration and its sequestration rate. Use of organic manure and compost enhances the SOC pool more than application of the same amount of nutrients as inorganic fertilizers (Gregorich *et al*., 2001) [2]. Organic matter plays a vital role for crop production. Due to huge demand of chemical fertilizer, consequently changing scenario of soil fertility management, the organic fertilizers can play a vital role in restoring fertility as well as organic matter status of the cultivating soils. In addition to manure and fertilizers, cropping sequence, duration and timings of 'fallowing' etc. can also affect the SOC stocks. Soil C sequestration is a multiple purpose strategy. It restores degraded soils, enhances the land productivity, improves the diversity, protects the environment and reduces the enrichment of atmospheric CO_2, hence shifts emission of GHGs and mitigates climate change (Wang *et al*., 2010) [16]. Integrated use of a balanced inorganic fertilizer in combination with lime and organic manure sustains a soil physical environment that is better for achieving higher crop productivity under intensive cropping systems in the hilly ecosystem of northeastern India (Saha *et al*., 2010) [11]. Keeping in view the importance of studying the effect of integrated nutrient management on carbon sequestration of food-forage intercropping system was proposed.

Materials and Methods

The investigation was carried out in the sandy loam soil of Assam Agricultural University, Jorhat, located at 26^0 45' N latitude and 94^0 12' E longitudes at an elevation of about 87 m above mean sea level. The soil was medium in organic carbon (0.52 and 0.53%) content, low in available nitrogen (207.50 and 213.47 kg/ha) and medium in available phosphorus (22.52 and 23.12 kg/ha), potassium (145.31 and 148.71 kg/ha), DTPA-Zn (1.25 and 1.26 mg/kg) and DTPA-Fe (116.33 and 120.51 mg/kg) with acidic (pH in 5.2 and 5.4) in reaction having 1.29 and 1.27 Mg/m^3 bulk density, Mean weight diameter 0.54 and 0.57 mm and biomass carbon 150.42 and 158.37 $\mu g\ g^{-1}$. The experiment was laid out in split plot design with three replications for two years. There were four main plot treatments comprising of sole crop oat, sole crop pea, different row proportion of oat and pea i.e. 3:2 and 3:3 along with four combinations of nutrient management *viz*. RDF (inorganics), 50% N of RDF + 50% N through FYM, 50 % N of RDF + 50% N through vermicompost and 50% N through FYM + 50% N through vermicompost were superimposed on each of the main plots as subplot treatments. The seeds of oat were treated with PSB and pea seeds were treated with PSB and Rhizobium culture @ 100g/kg seeds for all the treatment combinations before sowing of seeds.

Estimation of Carbon sequestration potential was done according to Pathak et al., 2011 [10] and Singh et al., 2014. The C sequestration was calculated only in terms of increase in C stock in soil. Emission of GHGs such as methane and nitrous oxide were not considered. Data on initial and final SOC concentrations in the NPK, NPK+vermicompost, NPK+FYM and NPK through vermicompost + FYM treatments were collected for all the treatments. The mass of SOC in the surface layer (0–15 cm) of soil was calculated as

$$MSOC = SOC \times BD \times T$$

Where

MSOC is mass of SOC ($Mg\ ha^{-1}$),
SOC is organic C concentration in soil (%),
BD is bulk density (Mgm^{-3}) and
T is thickness of surface layer (cm).

Carbon sequestration potential of the treatment was calculated as

$$CSP_{treatment} = MSOC_{treatment} - MSOC_{initial}$$

$MSOC_{treatment}$ was final SOC in the mineral or mineral + organic treatment (Mg/ha) and $MSOC_{initial}$ was initial SOC in the unfertilized soil at the beginning of the experiment in Mg/ha.

Result and Dicussion

Bulk density of the soil, Organic carbon (OC) content, Microbial biomass carbon (MBC) and Carbon sequestration potential in the soil as influenced by cropping systems and integrated nutrient management (INM)

Bulk Density (BD) (g/cm^3) of the soil as influenced by intercropping and INM

The bulk density of the soil as influence by intercropping was found to be non-significant in both the years of experimentations. However the lowest BD of 1.17 and 1.16 g/cm^3 at 0-15 cm and 1.21 and 1.19g/cm^3 at 15-30 cm was recorded during 2014-15 and 2015-16, respectively. Among the intercropping systems the lowest BD was observed at 3:3 row proportions of oat+pea intercropping systems during the two experimental years.

Integrated nutrient management of the soil with 50% N through vermicompost + 50% N through inorganics recorded the lowest BD and compared to the RDF from only inorganic sources. The decrease in BD of 8.80 and 8.13 percent at 0-15 cm depth soil was recorded in 2014-15 and 2015-16, respectively. A similar trend of observations was also recorded in 15-30 cm depth soil in both the years of experimentations. The reduction of soil bulk density may be due to increasing organic matter which improved soil aggregation and porosity of the soil (Kharche *et al*., 2013). The organic fertilizer treatments improved soil aggregate stability and soil microbiological properties compared to NPK treatments. This finding is in corroboration with the findings of Wang *et al*., 2013 [15].

Soil organic carbon (OC) fractions as influenced by intercropping and INM

Organic carbon is an important indicator of soil fertility and productivity because of crucial role of soil chemical, physical and biological properties. Increasing OC not only contributes the long term health and quality of the soil, but also improves crop production. The OC content of soil under intercropping system was significantly higher in the sole pea cropping in both the years of experimentations. Among the different intercropping systems the highest was observed in 3:3 row proportions of oat+pea intercropping systems showing the value of 0.62 and 0.64% during 2014-15 and 2015-16, respectively. The lowest organic carbon was observed in sole oats in both the years.

Soil organic carbon due to integrated nutrient management was recorded to be highest in F_3 (50% N through vermicompost + 50% N through inorganics) in both the soil depths of 0-15 and 15-30 cm during the two years of experimentations. F_2 (50% N through FYM + 50% N through inorganic fertilizers) also give significantly higher OC over 100% inorganic fertilizer amendments in both the years. A similar trend of observations was recorded in 15-30 cm soil depths in both the years of experimentations. Addition of vermicompost @ 5t/ha increased organic carbon in soil (Srikanth *et al*. 2000). Use of organic manures and compost enhances the soil organic carbon pool more than application of the same amounts of nutrients as inorganic fertilizers (Gregorich *et al*., 2001) [2]**.** In the presence of vermicompost, the microorganisms get enough food and suitable media proliferate to both interms of their number and activity, thus increase the organic status of the soil and made nutrients available to growing plants.

Microbial biomass carbon (MBC) as influenced by intercropping and INM

The microbial biomass carbon as affected by intercropping systems was found to be significant in both the years of experimentations. The highest MBC of 270.39 and 279.32µg/g for 0-15 cm soil depth and 252.51 and 260.12µg/g for 15-30 cm soil depth was recorded in sole pea culture during 2014-15 and 2015-16, respectively which was followed by 3:3 row proportions of oat+pea intercropping systems.

MBC was influence significantly by integrated nutrient management and was found to be highest in F_3 (50% N through vermicompost + 50% N through inorganic fertilizer) showing the value of 305.51 and 314.44µg/g was recorded at 0-15 cm soil depth during 2014-15 and 2015-16, respectively and the lowest was being recorded in F_1 (RDF) at 0-15 cm. A similar trend of observation was recorded in 15-30 cm soil depth during the years of experimentations. The integrated fertilizer regimes stimulated the microbial growth, altered the structure of soil microbial community and increased enzyme activity relative to inorganic fertilization (Lazcano, *et al*., 2013) [7]. The application of organic fertilizers increased the organic carbon content of the soil and thereby increasing the microbial biomass carbon whereas the use of inorganic fertilizers resulted in low organic carbon content and microbial biomass carbon of the soil, although it increased the soil's nitrogen, phosphorus and potassium level which could be explained by the rates of fertilizers being applied.

Carbon sequestration potential as influenced by intercropping and INM

Effect of intercropping on carbon sequestration potential was found to be significant during the years of experimentation. The highest CSP of 1.24 and 1.33Mg/ha was observed in sole pea at 0-15 cm soil depth during 2014-15 and 2015-16, respectively. The lowest CSP was being observed in sole oats, among the intercropping the highest was recorded in 3:3 over 3:2 row proportions of oat+pea intercropping systems. Intercropping oats and pea is an efficient strategy to increase land productivity, grain and biomass quality, N and C yields and sequestered higher C in soil compared to monoculture oats. A similar finding was reported by Chapagain and Riseman, 2014. High intensive cropping system with addition of organic along with inorganic fertilizers maintained soil quality parameters, which in turn supports better crop productivity and carbon sequestration (Manna *et al*. 2012) [9].

Integrated nutrient management on carbon sequestration was significantly higher in the treatment combinations of 50% N through vermicompost + 50% N through inorganics which was followed by F_2 (50% N through FYM + 50% N through inorganic fertilizer), the lowest CSP was recorded in 100% inorganic fertilizers during the years of experimentations. Addition of organic manures resulted in higher carbon sequestration similar findings were also reported by Singh *et al*., 2011 [12]. The higher carbon sequestration obtained due to 50% N through vermicompost + 50% N through inorganic might be the results of higher biomass production through application of optimal dose of fertilizers in combination with organics which led to an additional buildup of SOC a major contributor in carbon sequestration. Lal (2004) [5, 6] summarized the results of a number of studies and concluded that improved fertility management can enhance the SOC content at the rate of 0.05 to 0.15 Mg/ha/year to the soil through only crop roots. The integrated use of cattle manure and NPK fertilizers is the most efficient management practice in improving carbon sequestering.

Conclusions

Based on the two year experimentation, it can be concluded that, in the rice-fallow systems, introduction of food-forage intercropping systems having component crop of oat and pea with planting geometry of 3:3 row proportion having considerable positive effect on bulk density, soil organic carbon content, microbial biomass carbon and carbon sequestration potential.

Integrated nutrient management of the soil with 50% N through vermicompost + 50% N through inorganics recorded significantly higher better bulk density, soil organic carbon content, microbial biomass carbon and carbon sequestration potential in all the experimental years.

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