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Effect of carbon sequestration management practices on growth, yield attributes and yield of maize in maize-potato-green gram cropping system

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Abstract
A field experiment was conducted on sandy loam soils of Students' Instructional Farm, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, during *kharif* 2021-22 and 2022-23 to find out the Effect of carbon sequestration management practices on growth, yield attributes and yield of maize in maize-potato-green gram cropping system. The green gram crop residue was incorporated in soil ten days before sowing of maize either alone or in combination with microbial consortia, organic based product and 100% RDF (120:60:60) as decomposition accelerators. Pooled data from a two-year study demonstrated that diverse carbon sequestration management practices resulted in significant enhancements in growth characteristics at various development stages, yield-attributing characters, and grain and stover yield of maize. Among the treatments, the highest plant height (224.60 cm), dry matter accumulation (1604.36 g m^{-2}), leaf area index (4.91), Chlorophyll intensity (41.68%) as well as crop growth rate (24.39 g m^{-2} day^{-1}) was recorded with the treatment where crop residue incorporation + fungal consortium @ 1 kg ha^{-1} **+** bacterial consortium @ 1 kg ha^{-1} + 100% RDF were applied followed by the application of crop residue incorporation + bacterial consortium @ 1 kg ha^{-1} + 100% RDF were applied, both were statistically at par with each other while significantly superior over rest of the treatments. Similar trend was also recorded for number of grain rows cob^{-1}, number of grains row^{-1}, cob's length, test weight, grain as well as stover yield during both the years. Thus, crop residue treated with microbial consortia incorporated along with 100% RDF practice is viable option of carbon sequestration management to achieve higher growth, yield attributes and yield from maize in maize-potato-green gram cropping system.

Keywords: carbon sequestration, consortium, growth, maize, residue incorporation, yield

1. Introduction

Over the past forty years, a variety of problems with soil quality have arisen as a result of ongoing cropping, endangering the viability of rice-based cropping systems (Srinivasan *et al.*, 2012) [18]. In order to address the problems of energy and nutritional security, residue burning, the loss in biomass production, and water tables, maize-based cropping systems are being promoted as an alternative to traditional rice-based cropping systems. One of the key cereal crops that sustains the global agricultural economy is maize (*Zea mays* L.). In India, maize is considered as promising option for diversifying agriculture in upland areas. Maize occupies an area of 10.4 mha with production and productivity of 33.62 mt and 3349 kg ha^{-1}, respectively (Anonymous, 2022) [1]. Conventional agriculture typically results in soil carbon depletion and reduced productivity.

Carbon sequestration in soil and its biomass has been to be a key strategy to reduce atmospheric CO_2. The term 'carbon sequestration' is used to describe the process by which CO_2 is either removed from the atmosphere or diverted from the emission sources and stored in the ocean, terrestrial environments (vegetation, soils and sediments) and geological formations. Soil carbon sequestration will account for about 90% of the total global mitigation potential in agriculture by 2030 (Smith, 2008) [17].

Soil carbon capture capability may be increased and improved by better farming techniques that restore soil fertility and health. Promoting sustainable agricultural production has several benefits, including increased crop and soil productivity, adapting climate change resilience, atmospheric carbon sequestration, and lower greenhouse gas concentrations in the atmosphere. To harness the carbon sequestration capacity of soil, the cultivation of plants with higher biomass production capability must be promoted in the agricultural system. (FAO & ITPS, 2015) [3]. Crop residues are one of the chief sources of carbon in agricultural soils. Agricultural crops produce a considerable quantity of residues, which in turn favours the accumulation of humus in consequent soil carbon pool upon incorporation into soil (Hajduk *et al.*, 2015; Meena & Yadav, 2014) [6, 11]. Utilization of crop residues for the succeeding crop in a cropping system is an alternative organic source of nutrients for sustaining soil health. Crop residue incorporation in maize based cropping system resulted in maximum growth and yield (Meena *et al.*, 2015) [11] and also improved soil properties by increasing productivity, protein yield, energy output, soil organic carbon, soil N, P and K, population of bacteria, fungi, actinomycetes, microbial biomass, and CO_2 evolution in soil (Sharma *et al.*, 2009) [16].

Crop residues have been found to decompose more effectively when lignocellulolytic microbe consortia are involved (Sahu *et al.*, 2020) [14]. Fungi and actinobacteria are potent in the degradation of complex ligno-cellulosic materials present in crop residues (Arcand *et al.*, 2016) [2]. This necessitated the use of microbial consortia developed by a combination of potent strains of fungi which can perform harmoniously for rapid decomposition of crop residues without any chemical pre-treatment (Kumar *et al.*, 2008). Residue management is gaining popularity these days due to its many implications on soil qualities. On terms of managing straw on the field itself, there are two possibilities. It can either be left on the surface or integrated into the soil. Therefore, the purpose of this study was to determine the effect of carbon sequestration management practices on growth, yield attributes and yield of maize in a maize-potato-green gram cropping system.

2. Materials and Methods

2.1 Study site

The experiment was conducted during the *kharif* season of 2021-22 and 2022-23) at Students' Instructional Farm, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, which is situated in the alluvial tract of Indo - Gangetic plains in central part of Uttar Pradesh between 25° 26' to 26° 58' North latitude and 79° 31' to 80°34'East longitude at an elevation of 125.9 meters from the sea level. This region falls under agro-climatic zone V (Central Plain Zone) of Uttar Pradesh.

2.2 Climate

This zone has semi-arid climatic conditions having alluvial fertile soil. The average maximum temperature 33.09 ^{0}C and minimum temperature 24.54 ^{0}C. The total rainfall recorded was 935.10 mm and 1106.10 mm with average relative humidity during the experimental season fluctuated between 60 to 84% and 60 to 86.5% during 2021 and 2022 respectively.

2.3 Properties of the experimental area soil

Before the initiation of the actual experiment, greengram crop was grown uniformly with traditional farmers practice for homogenization of soil fertility and collection of residues for the experiment. The soil of the experimental field was sandy loam in texture, well drained, plane topography, slightly saline in nature having initial values pH (7.76 and 7.72), EC (0.45 and 0.44 dsm^{-1}), low in organic carbon (0.45 and 0.46%), low in available nitrogen (193.99 and 198.01 kg ha^{-1}), medium in phosphorus (14.13 and 14.21 kg ha^{-1}) and Potash (157.31 and 156.25 kg ha^{-1}) during 2021 and 2022 respectively.

2.4 Experimental Details

The experiment was laid out in a randomised block design (RBD) and replicated three times using the residue obtained from green gram grown in zaid season, comprising eleven treatments consisting of T_1: Absolute Control, T_2: 100% RDF, T_3: crop residue incorporation + 100% RDF, T_4: crop residue incorporation + Ghana jeevamrit @ 0.5 t ha^{-1}, T_5: Crop residue incorporation + jeevamrit @ 500 litre ha^{-1}, T_6: Crop residue incorporation + fungal consortium @ 1 kg ha^{-1} + 100% RDF, T_7: Crop residue incorporation + bacterial consortium @ 1 kg ha^{-1} + 100% RDF, T_8: Crop residue incorporation + fungal and bacterial consortium each @ 1 kg ha^{-1} + 100% RDF, T_9: Crop residue incorporation + fungal consortium @ 1 kg ha^{-1}, T_{10}: Crop residue incorporation + bacterial consortium @ 1 kg ha^{-1}, and T_{11}: crop residue incorporation + fungal and bacterial consortium each @ 1 kg ha^{-1}. The biomass of greengram obtained during *zaid* including stubbles were removed from field, chopped into 3 to 4 cm pieces and incorporated with rotavator to a depth of 15 cm of the soil in the field after quantification except in T_1 (Absolute control) and T_2 (100% RDF) treatments. The required quantity of different treatments viz., crop residue, fungal and bacterial consortium incorporation and as per the treatments was applied in field ten days before sowing of the crops.

The 100% recommended fertilizer dose (RDF) for maize crop [120kg N: 60kg P_2O_5 and 60kg K_2O ha^{-1}] were applied as per the treatments. The Jeevamrit was applied to the crop twice (at 20 and 45 DAS) as a foliar spray at 500 litre ha^{-1} after irrigation in respective treatments. Ghana Jeevamrit is a dry or solid form of Jeevamrit that is just as effective on the soil. The powdered form of Ghana jeevamrit administered as per treatments at the time of sowing @ 0.5 t ha^{-1}. Fungal and bacterial consortium was applied @ 1 kg ha^{-1} either alone or in combination with 100% recommended dose of fertilizer (RDF) as per the treatments. The formulation of fungal consortium consists of *Aspergillus sp.*, *Phanerochaete sp.*, & *Trichoderma sp.*, and bacterial consortium of *Bacillus* sp, & *Pseudomonas* sp developed at Bio control Lab of CSA University Agriculture & Technology, Kanpur, India. All the recommended agronomic practices were adopted to raise the crop.

2.5 Data collection and analysis

The observations for each treatments on growth parameters *viz.*, number of plant m^{-2}, plant height, Dry matter accumulation, leaf area index, chlorophyll intensity and crop growth rate, and yield attributes *viz.*, number of cobs plant^{-1}, number of grain rows cob^{-1}, number of grains row^{-1}, cob's length and test weight were recorded following standard procedures. For determining the growth and yield attributing characters five plants from each plot were randomly selected and tagged in second row of either side in the field. Dry matter accumulation (DMA) and leaf area index studies were done from the randomly selected three plants from second row maize. To determine grain yield, the kernels of each net plot's air-dried cobs were separated, dried, and threshed after adequate cleaning to get 14% moisture. The weight of grains from each plot was recorded independently and represented as grain yield in t ha^{-1}. Stover from the net plot area was weighed after complete drying in the sun and expressed as stover yield in t ha^{-1}. The data collected from the experiments were subjected to statistical analysis by applying the procedure for randomised block design. Overall differences were tested by 'F' test at 5% level of significance as suggested by (Gomez & Gomez, 1984). In case of significant result, critical difference at 5% level of probability was also calculated for testing the significance between two treatment means.

3. Results and Discussion

3.1 Effect on growth attributes

An overview of pooled data in Table-1 showed that the effect of various treatments of carbon sequestration management practices with respect to growth attributing characters such as plant height, dry matter accumulation, leaf area index, Chlorophyll intensity as well as crop growth rate were found significant at all the growth stages of crop except number of plants m^{-2} which did not differed significantly due to different treatments of carbon sequestration management practices. Among various treatment, the maximum plant height (224.60 cm), dry matter accumulation (1604.36 g m^{-2}), leaf area index (4.91), Chlorophyll intensity (41.68%) as well as crop growth rate (24.39 g m^{-2} day^{-1}) was recorded with the treatment where crop residue incorporation + fungal consortium @ 1 kg ha^{-1} + bacterial consortium @ 1 kg ha^{-1} + 100% RDF were applied followed by the application of crop residue incorporation + bacterial consortium @ 1 kg ha^{-1} + 100% RDF were applied, both were statistically at par with each other while significantly superior over rest of the treatments. The minimum growth attributes was recorded with the control plots at all growth stages of crop. This might have resulted in more photosynthetic cell division and production at appropriate stages of development. Furthermore, the enlarged organic pool in the soil may have boosted the activity of beneficial bacteria, resulting in the generation of growth-promoting compounds and better nutrient availability for a longer length of time during crop growth (ICAR News, 2008). The results were corroborated with the findings of Wong *et al.* (2015) [20], Kaur and Reddy (2017) [17], Yasmeen *et al.* (2018) [21], Goud *et al.* (2022) [5], Kumari *et al.* (2022) [9], Shahin et al. (2022) [15] and Latha *et al.* (2023) [10].

3.2 Effect on yield attributes

The pooled data of two year (Table-2) clearly indicate that various treatments of carbon sequestration management practices showed significant improvement in yield attributes *viz.*, number of grain rows cob^{-1}, number of grains row^{-1}, cob's length as well as test weight than control except number of cobs $plant^{-1}$ which did not differed significantly due to different treatments of carbon sequestration management practices. Among various treatments, the maximum number of grain rows cob^{-1} (13.17), number of grains row^{-1} (26.42), cob's length (16.41 cm) as well as test weight (225.87 g) was recorded with the treatment where T_8: [crop residue incorporation + fungal and bacterial consortium each @ 1 kg ha^{-1} + 100% RDF] were applied followed by the treatment where T_7: [crop residue incorporation + bacterial consortium @ 1 kg ha^{-1} + 100% RDF] were applied, both were statistically at par with each other while significantly superior over rest of the treatments. This might be due to increased absorption and utilization of available nutrients, resulting in total crop growth improvement as shown by the source-sink relationship, which in turn improved maize yield parameters. The findings are comparable with Yasmeen et al. (2018) [21], Goud *et al.* (2022) [5], Kumari et al. (2022) [9], Rajitha *et al.* (2022) [13], Shahin *et al.* (2022) [15] and Vaishnav *et al.* (2022) [19].

Table 1: Effect of carbon sequestration management practices on growth attributes of maize (Pooled data of two year)

Treatments	Number of plants m^{-2}	Plant height (cm.)	Dry matter accumulation (g m^{-2})	Leaf Area index	Chlorophyll intensity	Crop growth rate (g m^{-2} day^{-1})
	At harvest	At harvest	At harvest	At 60 DAS	At 45 DAS	At 60-harvest
T_1	7.48	157.94	1086.75	3.45	31.41	16.52
T_2	7.60	205.83	1439.91	4.50	38.20	21.89
T_3	7.63	209.46	1477.74	4.61	39.07	22.47
T_4	7.57	196.19	1366.50	4.22	36.41	20.79
T_5	7.55	190.97	1328.71	4.14	35.48	20.20
T_6	7.68	215.02	1521.48	4.71	39.93	23.13
T_7	7.73	220.14	1566.11	4.82	40.85	23.81
T_8	7.76	224.60	1604.36	4.91	41.68	24.39
T_9	7.50	178.94	1236.93	3.93	33.22	18.81
T_{10}	7.52	182.11	1261.25	3.96	33.84	19.18
T_{11}	7.53	186.47	1292.79	4.03	34.65	19.66
SEm±	0.08	1.98	15.94	0.04	0.33	0.24
C.D (p=0.05)	NS	5.67	45.55	0.11	0.95	0.69

*RDF= Recommended dose of fertilizer, T_1: Absolute Control, T_2: 100% RDF, T_3: crop residue incorporation + 100% RDF, T_4: crop residue incorporation + Ghana jeevamrit @ 0.5 t ha^{-1}, T_5: Crop residue incorporation + jeevamrit @ 500 litre ha^{-1}, T_6: Crop residue incorporation + fungal consortium @ 1 kg ha^{-1} + 100% RDF, T_7: Crop residue incorporation + bacterial consortium @ 1 kg ha^{-1} + 100% RDF, T_8: crop residue incorporation + fungal consortium @ 1 kg ha^{-1} + bacterial consortium @ 1 kg ha^{-1} + 100% RDF, T_9: Crop residue incorporation + fungal consortium @ 1 kg ha^{-1}, T_{10}: Crop residue incorporation + bacterial consortium @ 1 kg ha^{-1}, and T_{11}: crop residue incorporation + fungal consortium @ 1 kg ha^{-1} + bacterial consortium @ 1 kg ha^{-1}

3.3 Effect on yield

Grain as well as stover yield were influenced significant improvement due to different carbon sequestration management practices than control (Table 2). The grain yield (4.85 t ha^{-1}) as well as straw yield (7.93 t ha^{-1}) were recorded highest in T_8: [crop residue incorporation + fungal and bacterial consortium each @ 1 kg ha^{-1} + 100% RDF] which was statistically at par with the treatment T_7: [crop residue incorporation + bacterial consortium @ 1 kg ha^{-1} + 100% RDF] and significantly superior over other carbon sequestration management practices. Incorporating crop residue with a fungal and bacterial consortium, as well as applying 100% RDF, may have increased the rate of decomposition of crop residue, resulting in a higher uptake of available nutrients from the soil and increased yield components, which may ultimately be attributed to higher grain and stover yield. The findings and the outcomes are comparable with Yasmeen et al. (2018) [21], Rajitha *et al.* (2022) [13], Shahin *et al.* (2022) [15] and Vaishnav *et al.* (2022) [19].

Table 2: Effect of carbon sequestration management practices on yield attributes, grain and stover yield of maize crop (Pooled data of two year)

Treatments	Number of cobs plant^{-1}	Number of grain rows cob^{-1}	Number of grains row^{-1}	Length of Cob (cm)	Test weight (g)	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})
T_1	1.00	9.76	19.58	12.47	182.54	2.65	6.00
T_2	1.07	12.07	24.21	15.02	212.16	4.09	7.38
T_3	1.13	12.35	24.76	15.33	214.58	4.25	7.52
T_4	1.07	11.51	23.08	14.10	205.18	3.76	7.13
T_5	1.07	11.21	22.49	13.72	200.90	3.57	7.01
T_6	1.13	12.62	25.31	15.70	219.20	4.47	7.65
T_7	1.13	12.91	25.90	16.05	223.37	4.68	7.80
T_8	1.17	13.17	26.42	16.41	225.87	4.85	7.93
T_9	1.00	10.47	20.99	13.13	190.75	3.16	6.70
T_{10}	1.00	10.68	21.42	13.20	193.95	3.27	6.77
T_{11}	1.07	10.94	21.94	13.48	197.36	3.41	6.88
SEm±	0.04	0.11	0.21	0.14	1.64	0.08	0.05
C.D (p=0.05)	NS	0.30	0.61	0.40	4.68	0.22	0.15

*RDF= Recommended dose of fertilizer, T_1: Absolute Control, T_2: 100% RDF, T_3: crop residue incorporation + 100% RDF, T_4: crop residue incorporation + Ghana jeevamrit @ 0.5 t ha^{-1}, T_5: Crop residue incorporation + jeevamrit @ 500 litre ha^{-1}, T_6: Crop residue incorporation + fungal consortium @ 1 kg ha^{-1} + 100% RDF, T_7: Crop residue incorporation + bacterial consortium @ 1 kg ha^{-1} + 100% RDF, T_8: crop residue incorporation + fungal consortium @ 1 kg ha^{-1} + bacterial consortium @ 1 kg ha^{-1} + 100% RDF, T_9: Crop residue incorporation + fungal consortium @ 1 kg ha^{-1}, T_{10}: Crop residue incorporation + bacterial consortium @ 1 kg ha^{-1}, and T_{11}: crop residue incorporation + fungal consortium @ 1 kg ha^{-1} + bacterial consortium @ 1 kg ha^{-1}

4. Conclusion
On the basis of the results illustrated from the present investigation it can be concluded that growth parameter *viz.*, plant height, dry matter accumulation, leaf area index, Chlorophyll intensity as well as crop growth rate of maize were noticed superior with crop residue incorporation + fungal and bacterial consortium each @ 1 kg ha^{-1} + 100% RDF resulted higher yield attributes and better seed & stover yield. Thus, crop residue treated with microbial consortia incorporated along with 100% RDF practice is viable option of carbon sequestration management to achieve higher growth, yield attributes and yield from maize in maize-potato-green gram cropping system.

5. Conflict of Interests
The authors have declared no conflict of interests exist.

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