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Impact of carbon sequestration management techniques on yield and economics of maize in maize-potato-greengram 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 impact of carbon sequestration management techniques on maize yield and economics in the maize-potato-green gram cropping system. A week before to maize seeding, the crop residue from green gram was added to the soil. This may be done either alone or in conjunction with microbial (fungal and bacterial) consortia, organic based products, and 100% RDF (120:60:60) as decomposition accelerators. A two-year study's worth of combined data showed that different approaches to managing carbon sequestration improved maize production and profitability significantly. Among the treatments, the highest biological yield (12.78 t ha^{-1}), grain yield (4.85 t ha^{-1}), stover yield (7.93 t ha^{-1}) as well as harvest index (37.93%) were 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 gross return, net return, and B: C Ratio during both the years. In order to maximize maize productivity and economics in the maize-potato-green gram cropping system, it is therefore feasible to treat crop residue using microbial consortia incorporated in addition to 100% RDF technique.

Keywords: Carbon sequestration, consortium, yield, maize, residue incorporation, yield

1. Introduction
Maize (*Zea mays* L.) is part of the *Poaceae* family. One of the most significant cereal crops in the world, supporting the global agricultural economy. It is also regarded as the "Queen of Cereals". In India, maize is viewed as a feasible option for diversifying agricultural output in upland areas, occupying 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 is often associated with soil carbon depletion and reduced productivity. Thus, adopting rational farming techniques such as crop residue recycling (Blair *et al*., 2006) [3], manure application, and conservation tillage (Rudrappa *et al*., 2006) [12] will be a century-long requirement for enhancing soil quality and ecosystem function. However, the incorporation of organic materials is a management strategy that has the potential to enhance soil organic carbon content and improve soil quality. The process by which CO_2 is either removed from the atmosphere or redirected from emission sources and stored in the ocean, terrestrial habitats (vegetation, soils, and sediments), and geological formations is referred to as 'carbon sequestration'. By 2030, soil carbon sequestration will account for about 90% of total worldwide agricultural mitigation potential (Smith, 2008) [18]. Better farming methods that restore soil fertility and health can boost soil carbon capture capabilities. Promoting sustainable agricultural production provides a number of advantages, including enhanced crop and soil productivity, climate change resistance, atmospheric carbon absorption, and reduced greenhouse gas concentrations. To utilize the carbon sequestration capacity of soil, the growth of plants with higher biomass production capabilities must be encouraged in the agricultural system (FAO & ITPS, 2015) [4].

In agricultural soils, crop residues are one of the chief sources of carbon. Agricultural crops generate an enormous quantity of residue, which in turn encourages the accumulation of humus in the eventual soil carbon pool following integration into soil. (Hajduk *et al.*, 2015; Meena & Yadav, 2014) [6, 10]. About 30-40 percent of nitrogen, 25-30 percent phosphorus, 30-40 percent of sulphur and 75-80 percent of potassium uptake by cereal crops are retained in residues, making them valuable sources of nutrients (Singh & Sidhu, 2014) [17]. Fungi and actinobacteria are potent in the degradation of complex ligno-cellulosic materials present in crop residues (Arcand *et al.*, 2016) [2]. Crop residues have been found to decompose more effectively when lignocellulolytic microbe consortia are involved (Sahu *et al.*, 2020) [13]. 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) [7].
Crop residue incorporation in maize based cropping system resulted in maximum growth and yield (Meena *et al.*, 2015) [9] 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]. Residue management is gaining popularity due to the numerous consequences for soil quality. There are two approaches to manage straw in the actual field. It can be left on the surface or incorporated into the soil. The goal of this study was to assess the impact of carbon sequestration techniques on yields of maize and economics in a maize-potato-greengram cropping system.

2. Materials and Methods

The experiment was carried out during the kharif season (2021-22 and 2022-23) at Students' Instructional Farm, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, which is located in the alluvial tract of the Indo-Gangetic plains in central Uttar Pradesh between 25° 26' to 26° 58' North latitude and 79° 31' to 80° 34' East longitude at an elevation of 125.9 metres above sea level. This area is in Uttar Pradesh's agro-climatic zone V (Central Plain Zone). This zone has semi-arid climatic conditions with alluvial rich soil, with average maximum and minimum temperatures of 33.09 °C and 24.54 °C respectively. Total rainfall was 935.10 mm in 2021 and 1106.10 mm in 2022, with average relative humidity ranging from 60 to 84% in 2021 and 60 to 86.5% in 2022. Before the initiation of the actual experiment, a uniform green gram crop was cultivated in accordance with conventional farmer practices to homogenize soil fertility and gather residues for the experiment. The soil of the experimental field was sandy loam in texture, well drained, plane topography, slightly saline in nature with initial values of pH (7.76 and 7.72), EC (0.45 and 0.44 ds m^{-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.
The experiment was set up in a randomized block design (RBD) and replicated three times utilizing the residue collected from green gram cultivated in the *zaid* season, containing 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 liter 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}. Except for the T_1 (Absolute control) and T_2 (100% RDF) treatments, the biomass of green gram acquired throughout the *zaid* season, including stubbles, was taken from the field, cut into 3 to 4 cm pieces, and integrated with a rotavator to a depth of 15 cm of soil in the field after quantification. The appropriate quantity of several treatments, namely crop residue, fungal and bacterial consortium inclusion, was administered in the field ten days before crop planting. The maize crop treatments included the application of the 100% Recommended Dose of Fertilizer (RDF) [120kg N: 60kg P_2O_5 and 60kg K_2O ha^{-1}]. The powdered form of Ghana jeevamrit and Jeevamrit were applied according to the treatments at the time of sowing at 0.5 t ha^{-1} and as a foliar spray at 500 liter ha^{-1} after irrigation to the crop twice (at 20 and 45 DAS), respectively. As per the treatments, a fungal and bacterial consortium was applied @ a rate of 1 kg ha^{-1}, either alone or in combination with 100% RDF. All of the necessary agronomic procedures were used to raise the crop. Data on biological yield, grain yield, stover yield, and harvest index were collected at the harvest stage of the maize crop, along with their economic implications. Using the conventional ANOVA process, the data was statistically analyzed. The standard errors of mean were determined in each item of research, and the critical differences (CD) at the 5% level were worked out for comparing the treatment mean when the 'F' test proved to be significant.

3. Results and Discussion

3.1 Effect on yields

The pooled data of two year (Table-1) clearly indicate that various treatments of carbon sequestration management techniques showed significant improvement in yields *viz.*, biological yield, grain yield, stover yield as well as harvest index than control. The biological yield (12.78 t ha^{-1}), grain yield (4.85 t ha^{-1}), stover yield (7.93 t ha^{-1}) as well as harvest index (37.93%) 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 techniques. The extent of increase in grain and stover yield in crop residue incorporation + fungal consortium @ 1 kg ha^{-1} + bacterial consortium @ 1 kg ha^{-1} + 100% RDF (T_8) to the tune of 82.67% and 32.14% over control, 29.04% and 11.21% over T_4: crop residue incorporation + Ghana Jeevamrit @ 0.5 t ha^{-1}, 18.42% and 7.54% over T_2: 100% RDF, 3.61% and 1.74% over crop residue incorporation + bacterial consortium + 100% RDF (T_7), respectively. This might be attributed to the mineralization process, the release of secondary and micronutrients in addition to major nutrients, and a greater synchronisation of nutrient availability throughout time, resulting in improved plant development and higher yields. The findings are in agreement with the results of Yasmeen *et al.* (2018) [22], Goud *et al.* (2022) [5], Kumari *et al.* (2022) [8], Rajitha *et al.* (2022) [11], Shahin *et al.* (2022b) [12] and Vaishnav *et al.* (2022) [20].

Table 1: Effect of carbon sequestration management techniques on yield and economies of maize crop (Pooled data of two year)

Treatments	Biological yield (t ha^{-1})	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Harvest Index (%)	Gross Return (₹ ha^{-1})	Net Return (₹ ha^{-1})	B:C Ratio
T_1	8.66	2.65	6.00	30.65	59853	31320	1.10
T_2	11.47	4.09	7.38	35.69	89499	51622	1.36
T_3	11.77	4.25	7.52	36.12	92746	54826	1.45
T_4	10.89	3.76	7.13	34.49	82674	47787	1.37
T_5	10.58	3.57	7.01	33.74	78938	45589	1.37
T_6	12.12	4.47	7.65	36.82	97042	58595	1.52
T_7	12.47	4.68	7.80	37.50	101331	62845	1.63
T_8	12.78	4.85	7.93	37.93	104770	65747	1.68
T_9	9.85	3.16	6.70	32.03	70520	39275	1.26
T_{10}	10.05	3.27	6.77	32.57	72858	41556	1.33
T_{11}	10.30	3.41	6.88	33.14	75724	43879	1.38
S.Em±	0.19	0.08	0.05	0.27	1943	1346	0.02
C.D (*p*=0.05)	0.54	0.22	0.15	0.76	5554	3849	0.05

*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 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 consortium @ 1 kg ha^{-1} + bacterial consortium each @ 1 kg ha^{-1}

3.2 Effect on economics

The total cost of cultivation of maize varied due the variable carbon sequestration management techniques. The pooled data of two year (Table-1) clearly indicate that various treatments of carbon sequestration management techniques showed significant enhancement in gross return, net return as well as benefit cost ratio than control. Among various treatments, the maximum gross return (104,770 ₹ ha^{-1}), net return (65,747 ₹ ha^{-1}), as well as benefit: cost ratio (1.68 ₹ $₹^{-1}$ invested) were 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. This might be attributable to increased grain and stover yield fluctuations, as well as the related cost of cultivation in the various treatments. The results of Wen *et al.* (2015) [21], Sun *et al.* (2021) [19] and Shahin *et al.* (2022a) [14] are all in accord with the findings.

4. Conclusion

Based on the findings presented in this study, it can be said that the integration of crop waste along with a fungal and bacterial consortia each at a rate of 1 kg ha^{-1} and 100% RDF led to greater biological, grain, stover, and harvest index yields as well as improved economic returns. In order to maximize maize productivity and economics in the maize-potato-green gram cropping system, it is therefore feasible to treat crop residue using microbial consortia incorporated in addition to 100% RDF technique.

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

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