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Augmenting crop residue and nutrient management for sustainable maize-mustard cropping system

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Abstract
A field experiment was conducted during 2022-23 and 2023-24 at Instructional-cum-Research Farm, Raj Mohini Devi College of Agriculture and Research Station, Ambikapur, Chhattisgarh to study the effect of various residue and nutrient management options on performance of maize-mustard system. The trial consisted of twelve treatment combinations including four vertical factors *i.e.*, Residue removal, Residue incorporation, Residue incorporation + spray of microbial consortium on residue and Zero-tillage + residue retention and spray of microbial consortium on residue and three horizontal factors *i.e.*, 100% RDF, 100% RDN and P and 50% RDK and 75% RDF + 5 t FYM/ha arranged in strip plot design with three replications. The results revealed that significantly higher grain yield (6443 and 1150 kg/ha respectively), stover yield of maize and mustard, respectively and maize equivalent yield and production efficiency of system were obtained with adoption of residue incorporation + spray of microbial consortium, which was at par to residue incorporation and zero-tillage + residue retention and spray of microbial consortium. Among nutrient management options, grain yield (6882.1 and 1174.2 kg/ha), stover yield of maize and mustard, respectively and maize equivalent yield and production efficiency of system were recorded under 100% RDF. The highest gross return (₹ 139.8 and 68.80 × 10^3/ha) was recorded under residue incorporation + spray of microbial consortium, while net return (₹ 95.83 and 37.05 × 10^3/ha) and B: C ratio (2.36 and 1.34) were recorded maximum under zero-tillage + residue retention and spray of microbial consortium, followed by residue incorporation + spray of microbial consortium and residue incorporation. Among the nutrient management options, the 100% RDF treatment yielded the highest mean gross return (₹ 149.2 and 70.22 × 10^3/ha), net return (₹ 104.7 and 37.8 × 10^3/ha) and benefit-cost ratio (2.35 and 1.18) followed by 100% RDN and P with 50% RDK for maize and mustard, respectively.

Keywords: Cropping system efficiency, maize, microbial consortium, mustard, nutrient management and residue management

Introduction

Maize (*Zea mays* L.), a staple crop with significant yield potential, is the third most important cereal globally following wheat and rice (Prasanna *et al.*, 2020) [18]. It plays a crucial role in India's agricultural landscape, particularly in the *Kharif* season, contributing around 24% of the total cereal production (Sinha, 2018) [25]. Globally, maize cultivation spans 197.2 million hectares, with a total production of 1.148 billion tons and an average yield of 5.82 tons per hectare (FAOSTAT, 2020) [7]. India, with 5% of the world's maize acreage contributes 2% to global production. The country cultivates maize on approximately 9.72 million hectares, yielding 28.64 million metric tonnes, with an average productivity of 2,945 kg per hectare (Anonymous, 2020) [2].

Indian mustard (*Brassica juncea* L.), an essential oilseed crop ranks second in production after sunflower in India. It accounts for 28.6% of the total oilseed production in the country (Shekhawat *et al.*, 2012) [23]. With an area of 6.78 million hectares, India produces 9.12 million tons of mustard yielding an average of 1,345 kg per hectare (Anonymous, 2020) [2]. The leading mustard-producing states include Rajasthan, Uttar Pradesh, Madhya Pradesh, Gujarat, Assam, West Bengal, Punjab, and Maharashtra (Anonymous, 2019) [1].

Despite India's status as the third-largest producer of rapeseed and mustard, it still relies heavily on imports to meet its edible oil requirements (Jat *et al.*, 2021) [11]. The intensive rice-wheat cropping system, which poses a threat to agricultural sustainability, has led to a decline in soil fertility, groundwater levels, and energy crises. In response, diversified maize- based crop rotations along with conservation tillage practices like zero-till and permanent bed systems have been adopted to minimize adverse effects and maintain soil fertility (Biswakarma *et al.*, 2020) [5]. Nutrient management is critical in the maize-mustard cropping system as both crops are exhaustive in nature (Singh *et al.*, 2022) [13]. The removal of nutrients through continuous cropping necessitates the use of chemical fertilizers in conjunction with organic manures to sustain soil health and productivity (Namdeo *et al.*, 2021) [15]. Crop residue management, particularly in the context of zero tillage offers a sustainable approach to soil fertility management, conserving moisture and improving soil structure and nutrient availability (Bera *et al.*, 2017) [4]. The study aims to evaluate the impact of crop residue and nutrient management practices on the productivity and economics of the maize-mustard cropping system in the northern hill region of Chhattisgarh, India. It seeks to address the challenges of soil fertility decline and environmental sustainability in this critical agricultural region.

Materials and Methods

The study was carried out over two seasons, from 2022 to 2024, at the Research Farm of Raj Mohini Devi College of Agriculture and Research Station, Ambikapur, Chhattisgarh. The experimental field had a sandy-loam soil texture, classified as *Inceptisols*, with acidic pH levels (5.5), moderate organic carbon content (0.5%), low nitrogen availability (234.1 kg/ha), moderate phosphorus levels (12.9 kg/ha) and high potassium availability (244.3 kg/ha). The region experiences a semi-arid, sub-tropical climate with extreme temperatures both in summer and winter. Rainfall is primarily due to the South-West monsoon season occurring between June and October with an average of about 1400 mm. Temperatures can soar up to 44 °C in the summer and drop to as low as 4-5 °C in winter, with relative humidity reaches 74%. The experiment was conducted using a strip plot design with three replications. It involved twelve treatment combinations of four vertical factors: residue removal, residue incorporation, residue incorporation + application of microbial consortium on the residue, and zero-tillage + residue retention and application of a microbial consortium on the residue and three horizontal factors: 100% RDF, 100% RDN and P and 50% RDK, and 75% RDF + 5 tons of FYM/ha. Sowing of maize cultivar NK 30 and mustard cultivar Chhattisgarh sarson-1 were done manually by using 20-25 and 6 kg seed ha^{-1} by maintaining 75cm x 20cm and 40cm x 10cm spacing, respectively. Recommended dose of fertilizer of 120:60:40 kg and 80:40:40 kg N: P_2O_5:K_2O/ha were applied as per the treatment in maize and mustard, respectively. Effect of above-mentioned treatments on test weight, yield and economic feasibility were computed. The cropping system efficiency in regards to maize equivalent yield and production efficiency were calculated by the formula suggested by Verma and Modgal (1983) [27] and Tomar and Tiwari (1990) [26], respectively as follows:

$$\text{MEY (t ha}^{-1}) = \text{Yield of maize (kg ha}^{-1}) + \frac{\text{Mustard seed yield } (\text{kg ha}^{-1}) \text{ x Mustard price (Rs.)}}{\text{Maize price (Rs.)}}$$

$$\text{Production efficiency (kg ha}^{-1}\text{ day}^{-1}) = \frac{\text{Economic yield of system}}{\text{Duration of cropping sequence}}$$

The influence of treatment was tested with 'F' test, which shown their significance, the levels of treatment were compared by critical difference at 5% level of probability (Gomez and Gomez, 1984) [8].

Results and Discussion

Yield attributes of Maize

For maize, the adoption of crop residue incorporation + spray of a microbial consortium resulted in significantly higher test weight, grain yield and stover yield which was statistically comparable to that of residue incorporation and zero-tillage with residue retention and spray of a microbial consortium. Test weight and harvest index doesn't show significant results among treatments (Table 1). The highest mean gross return was observed under residue incorporation + spray of a microbial consortium, with ₹ 139.8 × 10^3/ha. However, the maximum net return of ₹ 95.82 × 10^3/ha and benefit-cost ratio of 2.36 were recorded under zero-tillage + residue retention and the spray of a microbial consortium, followed by residue incorporation + the spray of a microbial consortium. The lowest performance in these parameters was noted under residue removal. Among the nutrient management options the application of 100% RDF yielded the highest grain yield, stover yield, gross return of ₹ 149.2 × 10^3/ha, net return of ₹ 104.7 × 10^3/ha and benefit-cost ratio of 2.35, followed by 100% RDN and P with 50% RDK. The lowest values were observed in the treatment with 75% RDF + 5 t FYM/ha.

The enhanced yield performance of maize under the combination of zero-tillage, residue retention, and the application of a microbial consortium can be attributed to several synergistic effects. Zero-tillage preserves soil structure, reduces erosion and maintains moisture levels, which are essential for root development and nutrient uptake. Residue retention contributes organic matter to the soil, improving its fertility, water retention capacity, and microbial activity. The addition of a microbial consortium introduces beneficial microorganisms that facilitate nutrient cycling, enhance nutrient availability and suppress soil-borne pathogens. Together, these practices create a more favorable soil environment for maize growth, leading to improved yield attributes and yield. Bachmann and Friedrich (2002) [3] and Shafi *et al.* (2007) [22] also reported 17% and 23.7% yield increment under no tillage condition compared to conventional tillage, respectively. Piccoli *et al.* (2020) [17] also stated 12% improved maize yield by crop residue incorporation due to nutritional effects. The highest net return and benefit-cost ratio was observed with Zero-tillage + residue retention and microbial consortium spray which can be attributed to several factors. Zero-tillage reduces labor, fuel machinery costs and enhancing overall cost efficiency. Residue retention improves soil moisture conservation and organic matter content, promoting better crop growth and yield with reduced input costs. The addition of a microbial consortium spray enhances nutrient availability and disease resistance, further boosting yield and reducing the need for chemical fertilizers and pesticides. Sangar *et al.* (2005) [21] also reported that cost of cultivation was lowest under no-tillage and highest under conventional tillage in maize crop mainly through saving in cost for tillage practices and reduce diesel consumption. The application of 100% RDF enhances yield attributes and overall yield of maize crops due to optimal nutrient availability that meets the plant's physiological and metabolic demands. Nutrients like nitrogen, phosphorus and potassium, which are typically included in RDF, play crucial roles in various plant functions. Ramesh *et al.* (2023) [19] also stated that grain yield was significantly higher in 100% RDF + Vermicompost 7.5 t ha^{-1} followed by 100% RDF + FYM 15 t ha^{-1}. The superior performance of the 100% RDF treatment in terms of gross return, net return and benefit-cost ratio can be attributed to the optimal supply of essential nutrients, which enhance crop growth, yield and quality. Hashim *et al.* (2015) [9] and Yadav *et al.* (2022) [28] also confirmed the present findings.

Yield attributes of Mustard

For mustard, the integration of crop residue incorporation + spray of a microbial consortium led to significant increase in test weight, grain yield and stover yield (Table 1). This improvement was similar to the results achieved by residue incorporation and zero-tillage with residue retention and spray of a microbial consortium. Similarly, the application of 100% RDF resulted in significantly higher grain yield, stover yield. However, the test weight and harvest index were observed not to change significantly across the different treatments. The highest gross return for mustard was also recorded under residue incorporation plus the spray of a microbial consortium with ₹ 68.80 × 10^3/ha while the maximum net return of ₹ 37.05 × 10^3/ha and benefit-cost ratio of 1.34 were observed under zero-tillage + residue retention and the spray of a microbial consortium, followed by residue incorporation + spray of a microbial consortium. The lowest performance in these parameters was noted under residue removal. Among the nutrient management options, the application of 100% RDF yielded the highest gross return of ₹ 70.22 × 10^3/ha, net return of ₹ 37.79 × 10^3/ha and benefit-cost ratio of 1.18, followed by 100% RDN and P with 50% RDK. The lowest values were observed in the treatment with 75% RDF of NPK plus 5 t FYM/ha.

Residue incorporation combined with a microbial consortium application improves soil health by enhancing organic matter, structure, and nutrient retention creating an environment conducive to beneficial microbial activity. This activity boosts nutrient availability leading to improved plant growth and higher yields. Jakhar *et al.* (2018) [10] also reported that zero tillage with 4 tonnes ha^{-1} crop residue resulted in maximum yield attributes and yield. Zero-tillage with residue retention and microbial consortium spray minimizes soil disturbance, reduces costs, and enhances soil health and crop productivity. In contrast, while residue incorporation boosts yield, its additional tillage requirements lower net returns compared to zero-tillage methods. Karekar *et al.* (2022) [14] also confirmed the present findings. The superior performance of the 100% RDF treatment in maximizing yield attributes and grain and stover yield can be attributed to the balanced and sufficient supply of essential nutrients (N, P, K) that are crucial for plant growth and development. In contrast, the 75% RDF of NPK combined with 5 t FYM ha^{-1} likely provided an insufficient nutrient supply, particularly in terms of the readily available NPK required during critical growth stages. Kadam *et al.* (2022) [13] also reported the similar findings. The 100% RDF likely provided the highest returns because it ensures an optimal supply of all essential nutrients, enhancing mustard growth and yield. Om *et al.* (2013) [16] also obtained that the application of 60 kg N + 60 kg P_2O_5 ha^{-1} increased the mean net returns and B: C ratio by 59 and 16.8% and 26 and 4.5% over control and 30 kg N + 30 kg P_2O_5 ha^{-1}, respectively.

Cropping system efficiency

Residue incorporation + microbial consortium spray significantly enhanced maize equivalent yield (MEY) and production efficiency of the system outperforming residue removal. Likewise, applying 100% RDF resulted in higher MEY and production efficiency compared to reduced fertilizer doses combined with FYM (Table 1). These might be due to that residue incorporation and microbial consortia enhances soil organic matter content, improves soil structure, and fosters nutrient cycling thereby promoting better crop growth and productivity. Zero-tillage combined with residue retention preserves soil moisture, reduces erosion and minimizes soil disturbance thereby creating favorable conditions for crop growth and resource use efficiency. Sinha (2018) [25] and Jat *et al.* (2019) [12] also supported the findings. Further, the superior productivity indices observed with 100% RDF, followed by 100% RDN and P with 50% RDK, can be attributed to optimal nutrient availability and balanced plant nutrition. Maize and mustard crops require essential nutrients like nitrogen, phosphorus and potassium in adequate quantities for vigorous plant growth, enhanced photosynthesis, improved nutrient uptake efficiency and it ultimately increases productivity indices such as maize equivalent yield and production efficiency of the system. Chaturvedi and Kushwaha (2022) [6] and Roy *et al.* (2023) [20] are also in line with present findings.

Table 1. Effect of residue and nutrient management options on test weight, yields and economics of maize and mustard and overall productivity of maize-mustard cropping system (pooled data of 2 years)

Treatment	Maize							Mustard							Cropping system efficiency	
	Test weight (g)	Grain yield (kg/ha)	Stover yield (kg/ha)	Harvest index (%)	Gross return (₹ ×10^3/ha)	Net return (₹ ×10^3/ha)	Benefit-cost ratio	Test weight (g)	Grain yield (kg/ha)	Stover yield (kg/ha)	Harvest index (%)	Gross return (₹ ×10^3/ha)	Net return (₹ ×10^3/ha)	Benefit-cost ratio	MEY (kg/ha)	Production efficiency (kg/ha/ day)
Crop residue management																
Residue removal	264.1	5694	8277	40.7	123.7	80.30	1.84	3.3	999	4416	18.5	59.90	26.93	0.81	8468	29.7
Residue incorporation	275.9	6280	9052	40.9	136.4	92.22	2.08	3.5	1105	4780	18.8	66.15	32.50	0.96	9349	32.8
Residue incorporation + spray of microbial consortium	282.3	6443	9143	41.3	139.8	94.56	2.08	3.6	1150	4926	19.0	68.80	34.85	1.03	9639	33.7
Zero-tillage + residue retention and spray of microbial consortium	272.7	6276	9044	40.9	136.3	95.16	2.31	3.4	1080	4691	18.7	64.67	36.39	1.28	9276	32.7
SEm±	3.74	107	109	0.70				0.09	24	69	0.31				119	0.47
CD (P=0.05)	NS	370	376	NS				NS	81	238	NS				410	1.63
Nutrient management																
100% RDF	281.7	6882	9544	41.9	149.2	104.4	2.33	3.7	1174	5011	19.0	70.22	37.54	1.16	10144	35.8
100% RDN and P and 50% RDK	274.4	6090	8701	41.2	132.2	89.69	2.12	3.5	1054	4618	18.6	63.14	30.99	0.98	9018	31.7
75% RDF + 5 t FYM/ha	265.2	5547	8393	39.8	120.8	77.48	1.79	3.2	1022	4481	18.6	61.27	29.47	0.93	8388	29.1
SEm±	4.33	140	124	0.54				0.06	17	41	0.31				153	0.65
CD (P=0.05)	NS	549	487	NS				0.23	67	160	NS				601	2.55
								NS								

RDF, 120:60:40 kg and 80:40:40 kg $N:P_2O_5:K_2O$ kg/ha for maize and mustard, respectively; FYM, Farm yard manure; MEY, Maize equivalent yield

Conclusion

An experiment was conducted which shows the effect of the combination of crop residue incorporation and microbial consortium spray significantly enhanced production of maize and mustard, maize equivalent yield and production efficiency surpassing residue removal while the net return and B:C ratio were obtained maximum with zero tillage combined with residue retention and spray of microbial consortium. Additionally, application of 100% RDF yielded the highest crop performance, maize equivalent yield and production efficiency of system, outperforming reduced fertilizer rates combined with FYM.

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