Indian Journal of Agricultural Sciences **94** (1): 080–085, January 2024/Article
https://doi.org/10.56093/ijas.v94i1.143475

Effect of residue incorporation and INM on productivity of spring maize (*Zea mays*) in rice (*Oryza sativa*)-based cropping system

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Received: 09 October 2023; Accepted: 18 October 2023

ABSTRACT

A field experiment was conducted during 2019 and 2020 at the research farm of Punjab Agricultural University, Ludhiana, Punjab to study the effect of integrated nutrient management (INM) on grain yield, economics, and system productivity of spring maize (*Zea mays* L.) under residue incorporation in a diversified cropping system. The main plot consisted of 4 treatment combinations, viz. straw removal + 100% NPK + farmyard manure (FYM) @50 t/ha; straw removal + 150% NPK; straw incorporation + 100% NPK + FYM @50 t/ha; and straw incorporation + 150% NPK, while sub-plot consisted of 3 nutrient levels (75%, 100% and 125% NPK) applied to spring maize planted in a single row and double rows on bed. The results revealed that combined application of straw incorporation + 100% NPK + FYM @50 t/ha resulted in significantly higher grain yield (80.1 and 83.6 q/ha), net returns (259.9 and 300.2 $\times 10^3$ ₹/ha), benefit cost ratio (1.34 and 1.51) and system productivity (82.9 and 89.1 kg/ha/day) of spring maize and application of 125% NPK to double row on bed resulted in significantly higher grain yield (14.6%, 12.9%) and system productivity (5.4%, 4.7%) as compared to 100% NPK to single row on bed during 2019 and 2020, respectively. Residue incorporation along with INM increased grain yield, net returns, nutrient uptake and system productivity of spring maize.

Keywords: Grain yield, Integrated nutrient management, Net returns, Residue incorporation, Spring maize, System productivity

In India, rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) is the predominant cropping system occupying 12.3 million hectares of area and around 85% of this area falls under Indo Gangetic Plains (Bhatt *et al.* 2021). This has brought a number of ecological and environmental issues including depletion of ground water and low nutrient use efficiency which has increased the concern about detrimental impact of uncontrolled use of synthetic fertilizers on soil fertility (Aulakh *et al.* 2012). In India, the estimated cereal crop residues production is 361×10^6 kg/yr of which rice residue contribute to about 53% (Rathod *et al.* 2019). The main adverse effects of crop residue burning include the emission of greenhouse gases (GHGs) that contributes to the global warming, increased levels of particulate matter (PM) and smog that cause health hazards, loss of biodiversity of agricultural lands and the deterioration of soil fertility. There is an urgent need for residue management of different crops for stability and sustainability of the production system.

Crop diversification in agriculture can be regarded as the re-allocation of current crops/cropping systems/farm enterprises to some alternative crops. In context of crop diversification, the existing rice-wheat cropping system, rice-potato (*Solanum tuberosum* L.)-spring maize (*Zea mays* L.) is an important cropping system that can be practiced in Punjab region to obtain higher yields and profitability. Efficient nutrient management in India had played an outstanding role in achieving huge increase in food grain production from 52 million tonnes in 1951–52 to 280 million tonnes during 2020–21 (Anonymous 2021). Fertilizers cannot be avoided completely since they are the potential sources of primary and secondary nutrients. Contrarily, organic manures outplay in maintaining soil fertility1 status but have lower yield potential (Sharma *et al.* 2019). Integration of organic manure along with synthetic fertilizers and residue management in agricultural crop production systems assist to improve crop yield, soil structure, soil moisture conservation and soil microbial activity (Bhatt *et al.* 2020). The objective of the present experiment was to study the effect of residue incorporation and nutrient management on grain yield, economics and system productivity of spring maize in rice-potato-spring maize cropping system.

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MATERIALS AND METHODS

The field experiments were conducted during 2019

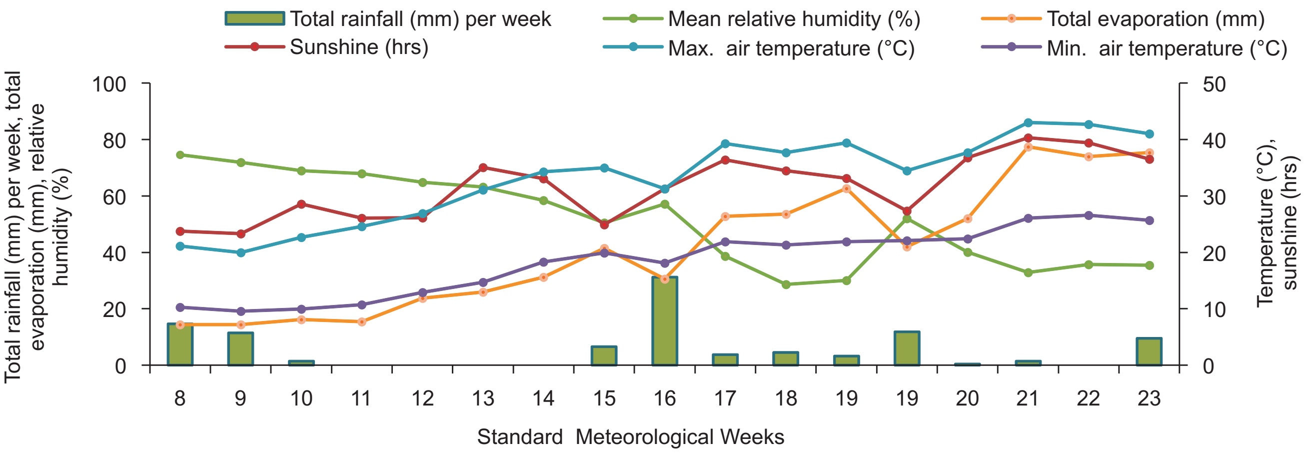

Fig. 1 Weather prevailing during crop growth period of spring maize during 2019.

and 2020 at the research farm of Punjab Agricultural University, Ludhiana (30°54' N latitude and 75°48' E longitude), Punjab, on a loamy sand soil in a diversified cropping system (rice-potato-spring maize) in a split plot design. Ludhiana is placed in the central plain region of Punjab under Trans Gangetic agro-climatic zone of India. It represents sub-tropical and semi-arid climate with very hot and dry summer from April to June, hot and humid conditions from July to September, cold winters from November to January and mild climate during February to March. It receives average annual rainfall of 755 mm and major portion (>75%) of the rainfall is received as summer monsoon from July to September. During the spring maize growing period the weekly mean maximum temperature ranged from 20.0–43.0°C and 18.9–41.3°C, while weekly mean minimum temperature ranged from 9.57–26.6°C and 4.91–23.7°C during 2019 and 2020, respectively. The maximum 74.6 and 73.4% weekly mean relative humidity was recorded during 8^{th} and 9^{th} week of crop season of 2019 and 2020. The minimum 28.6 and 30.1% weekly mean relative humidity was recorded during 18^{th} and 21^{st} week of crop season of 2019 and 2020. The total rainfall of 100.0, 147.6 mm was recorded during 2019 and 2020, respectively (Fig. 1 and 2).

Experimental site and design: The soil was low in organic carbon and available nitrogen, medium in available potassium and high in available phosphorus. The field experiment was laid out in split plot design (SPD) consisting of two crops i.e. rice and potato in main plots with 4 treatment combinations applied to potato, viz. M_1, straw removal + 100% NPK + FYM @50 t/ha; M_2, straw removal + 150% NPK; M_3, straw incorporation + 100% NPK + FYM @50 t/ha; and M_4, straw incorporation + 150% NPK and each main plot was divided into 6 sub-plots to allocate different treatments to bed planted spring maize, viz. S_1, 75% NPK with single row on bed; S_2, 75% NPK with double row on bed; S_3, 100% NPK with single row on bed; S_4, 100% NPK with double row on bed; S_5, 125% NPK with single row on bed; and S_6, 125% NPK with double row on bed during 2019 and 2020.

Grain yield: The grain yield was determined by sun drying the cobs from each net plot and shelled. The grain yield was adjusted to 15% of moisture level and expressed as q/ha. For recording stover yield, the remaining plant material including husk was sun dried, weighed and expressed in q/ha. Grain yield expressed as percentage of total biomass yield was taken as harvest index.

Spring maize equivalent yield (SMEY): Yield of

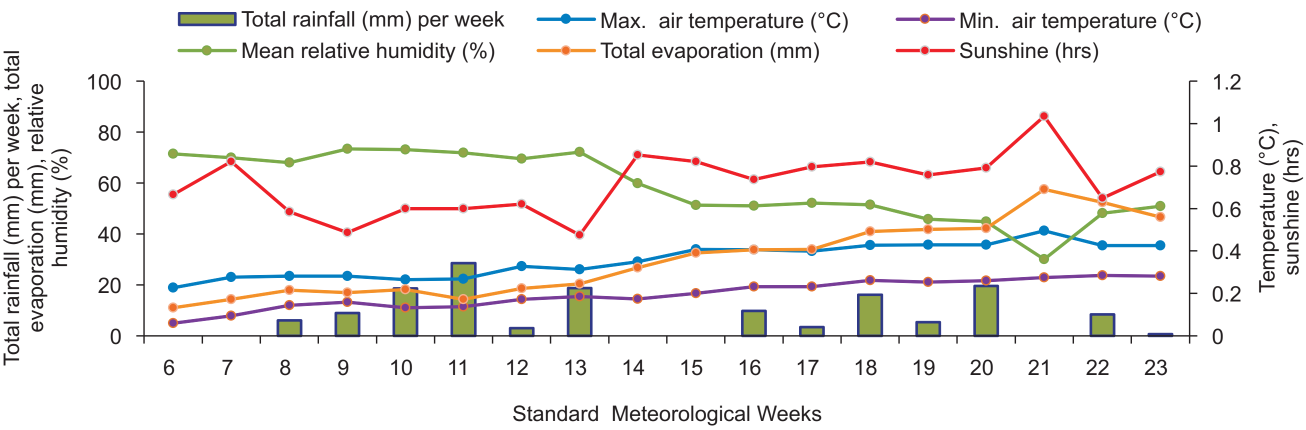

Fig. 2 Weather prevailing during crop growth period of spring maize during 2020.

various crops in the system were converted to spring maize equivalent yield (SMEY) on basis of market price of crops.

$$\text{SMEY (q/ha)} = \frac{\text{Grain yield of}}{\text{spring maize}} + \frac{\text{Grain yield of rice} \times \text{price of rice}}{\text{price of spring maize}} + \frac{\text{Yield of potato} \times \text{price of potato}}{\text{price of spring maize}}$$

System productivity: System productivity was calculated by dividing the spring maize equivalent yield with duration of the system:

$$\begin{matrix}\text{System productivity} \\ \text{(kg/ha/day)}\end{matrix} = \frac{\text{Spring maize equivalent yield of the system (q/ha)}}{\text{Duration of the system (days)}}$$

Economics: Gross returns were obtained by multiplying the quantity of output and market price. Net return was calculated by subtracting the total cost of cultivation from gross returns of the system. B:C is the ratio between net returns obtained from the system and the total cost of cultivation:

$$\text{Benefit : Cost} = \frac{\text{Net returns (₹/ha)}}{\text{Total cost of cultivation (₹/ha)}}$$

Profitability: The profitability of the system was calculated by dividing net returns of the system by 365 days and expressed as ₹/ha/day:

$$\text{Profitabilty} = \frac{\text{Net returns}}{\text{365 days}}$$

Statistical analysis: Analysis of variance was performed using procedure proposed by Cochran and Cox (1967). For analysis of data, statistical package CPCS-I, software was used developed by the Department of Mathematics and Statistics, PAU, Ludhiana. Treatment comparisons were made at 5 per cent level of significance.

RESULTS AND DISCUSSION

Effect of rice residue and nutrient application to preceding potato

Yield attributes: Maximum cob length, cob girth, numbers of grain per row, total number of grains per cob and 1000 seed weight (16.5 and 16.3 cm, 14.1 and 14.6 cm, 30.5 and 30.7, 440.0 and 449.0 and 250.9 and 258.4 g) were registered under 100% NPK + FYM @50 t/ha along with residue incorporation, followed by treatment consisting of residue removal + 100% NPK + FYM @50 t/ha and residue incorporation + 150% NPK during 2019 and 2020, respectively (Table 1). A significant increase in yield attributes from crop residue incorporated plot with 100% NPK + FYM @50 t/ha was due to efficient utilization of nutrients, which increases the rate of conversion of dry matter into economic yield. Combined application of organic and inorganic fertilizer enhances the root penetration for better nutrient and water uptake which had a positive effect on yield attributes of the plant. Combined application of organic and inorganic source of nutrients improved the cob length, girth and 1000-seed weight of spring maize (Almaz *et al.* 2017, Mahato *et al.* 2020, Niranjan *et al.* 2023).

Grain and stover yield: The grain and stover yield of spring maize were significantly higher in plots with residue incorporated with 100% RDF + FYM @50 t/ha applied to preceding crop (80.1 and 83.6 and 154.0 and 164.3 q/ha) as compared to residue removal + 150% NPK and it was statistically at par with treatment involving residue removal and application of 100% NPK + FYM @50 t/ha during 2019 and 2020, respectively (Table 2). The increase in grain yield was 10.6 and 14.6% in residue incorporated plot with 100% NPK + FYM @50 t/ha as compared to residue removed + 150% NPK application during 2019 and 2020, respectively.

The higher grain yield (Table 2) under residue incorporation and 100% NPK + FYM @50 t/ha applied plots was owing to combined effect of better growth and development resulted in more cob length and more numbers of grains per cob and ultimately led to more grain yield apart from better plant height, dry matter accumulation and leaf area index that led to higher stover yield. Ejigu *et al.* (2021) also reported higher maize grain and stover yield with combined application of organic manures and synthetic fertilizers than sole application of synthetic fertilizers.

Spring maize equivalent yield (SMEY) and system productivity: The results indicated that residue incorporation along with 100% NPK + FYM @50 t/ha applied to the preceding potato resulted in significantly higher SMEY (257.6 and 267.4 q/ha) and system productivity (82.9 and 89.1 kg/ha/day) as compared to 150% NPK applied with and without residue incorporation during 2019 and 2020, respectively (Table 2). Lowest SMEY was recorded with the application of 150% NPK without residue incorporation to preceding potato during both the years. Sepat *et al.* (2015) observed that combined application of organic and inorganic fertilizers resulted in higher wheat equivalent yield as compared to only application of inorganic fertilizer.

Economics: Application of 100% NPK + FYM @50 t/ha to the preceding potato crop along with straw incorporation resulted in maximum gross returns (453.3 and 499.6 ×10^3 ₹/ha), net returns (259.9 and 300.2 ×10^3 ₹/ha), B:C (1.34 and 1.51) and profitability (712.2 and 822.5 ₹/ha/day) followed by treatments involving 100% NPK + FYM @50 t/ha without residue incorporation during both the years (Table 3). Higher economic analysis of the cropping system under combined use of organic and synthetic fertilizer source was due to higher grain yield obtained under this treatment that fetched higher returns during both the years. Kumawat *et al.* (2019) revealed that combined application of organic and inorganic fertilizers resulted in higher gross returns, net returns and profitability as compared to sole application of synthetic fertilizers.

Table 1 Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on yield attributing characters of spring maize

Treatment	Cob length (cm)		Cob girth (cm)		Number of grains per row		Number of grains per cob		1000-seed weight (g)	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Rice residue and nutrient application to preceding potato										
M_1	16.1	16.2	13.8	14.4	29.1	30.0	414.4	433.0	247.1	255.2
M_2	15.6	15.6	13.1	14.0	27.9	28.8	376.7	409.8	239.1	246.3
M_3	16.5	16.3	14.1	14.6	30.5	30.7	440.0	449.0	250.9	258.4
M_4	15.9	16.0	13.3	14.2	28.7	29.4	397.2	420.5	241.9	251.4
LSD (P=0.05)	0.6	0.5	0.5	0.4	1.4	1.3	22.8	18.4	2.8	NS
Nutrient levels in spring maize										
S_1	16.5	16.1	13.6	14.3	29.7	30.8	419.9	451.9	246.5	256.4
S_2	14.0	14.0	12.6	13.5	24.6	25.4	317.4	340.4	234.8	235.2
S_3	17.1	17.2	14.1	14.8	30.8	31.9	449.4	468.6	249.8	260.2
S_4	14.8	14.9	12.8	13.7	28.0	27.8	367.9	388.6	235.5	244.1
S_5	17.7	17.8	14.5	15.3	32.5	33.8	487.4	498.8	259.6	269.0
S_6	16.1	16.2	13.8	14.3	28.6	29.0	400.5	420.1	242.1	252.2
LSD (P=0.05)	0.7	0.6	0.5	0.5	2.0	1.6	29.3	23.7	8.0	8.0
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Treatment details are given under Materials and Methods.

Effect of nutrient levels on spring maize

Yield attributes: The yield attributes of spring maize, viz. cob length, cob girth, numbers of grain per row, total number of grains per cob and 1000-seed weight increased with increase in nitrogen level but it decreased with increase in plant density. The yield attributes were significantly higher under 125% NPK applied to single row on bed, but was statistically at par with 100% NPK application to single row on bed during 2019 and 2020, respectively (Table 1). This could be owing to optimum utilization of solar radiation, higher assimilate production and their conversion to starches resulted in higher growth of the cob (Table 1). Golla *et al.* (2020) also recorded higher cob girth and 1000-seed weight with application of higher dose of nitrogen as compared to lower dose.

Grain and stover yield: Treatment involving application of 125% NPK to double row on bed resulted in significantly higher grain (85.4 and 87.5 q/ha) and stover yield (165.1 and 175.4 q/ha) as compared to all other treatment combinations during both the years (Table 2). The per cent increase in grain yield in 125% NPK applied to double row on bed was 25.0%, 25.7% and 14.6%, 12.9% as compared to 75% NPK and 100% NPK application to single row on bed (68.3, 69.6 q/ha and 74.5, 77.5 q/ha) during 2019 and 2020, respectively. The lowest stover yield (133.5 and 140.6 q/ha) was recorded from single row on bed with 75% NPK application during 2019 and 2020. Increasing nitrogen level up to 125% NPK to bed planted spring maize leads to higher grain yield due to better vegetative and reproductive growth of the plant. The increase might be due to increased availability of NPK, causing accelerated photosynthetic rate and thus leading to production of more carbohydrates and ultimately more yield. Similar findings were recorded by Adhikari *et al.* (2021). Moreover, Srivastava *et al.* (2018) recorded higher grain yield with increasing population density came mainly from more numbers of plant and cobs per unit area which resulted in enhancement of grain and biological yield.

Harvest index (HI): Rice residue and nutrient applied to preceding potato had no significant effect on harvest index of spring maize (Table 2). Whereas nutrient applied to spring maize had a significant effect on harvest index during both the years. Maximum HI was recorded under 125% NPK applied to single row planted spring maize which was at par with 100% NPK applied to single row planted maize and 125% NPK applied to double row planted spring maize during both the years. Higher HI under higher fertilizer dose might be due to adequate availability of nutrients that improved nutrient uptake and better photosynthetic rate which ultimately leads to higher harvest index. Similar results were recorded by Adhikari *et al.* (2021).

Spring maize equivalent yield (SMEY) and System productivity: Application of 125% NPK to double row on bed resulted in significantly higher SMEY (251.1 and 261.4 q/ha) and system productivity (81.3 and 87.1 kg/ha/day) as compared to lower nutrients levels i.e. 75% NPK, 100% NPK applied to both single and double rows on bed and 125% NPK applied to single row on bed during 2019 and 2020 (Table 2). The increase in SMEY and system productivity with application of 125% NPK to double row on bed was 4.6 and 4.0% and 5.4 and 4.7% higher as compared to application of 100% NPK to single row on bed during 2019 and 2020, respectively.

Economics: Application of 125% NPK to double row on bed resulted in maximum gross returns (441.8 and 488.2 $\times 10^3$ ₹/ha), net returns (250.2 and 290.8 $\times 10^3$ ₹/ha), B:C (1.30 and 1.47) and profitability (685.4 and 796.9 ₹/ha/day) and the per cent increase in gross and net returns, B:C and profitability with application of 125% NPK to double row on bed was 4.6 and 3.9%, 4.2 and 4.9%, 3.2 and 2.9% and 6.3 and 5.0% as compared to 100% NPK applied to single row on bed during both the years (Table 3). Adhikari *et al.* (2021) recorded higher gross returns and net returns at higher N dose as compared to lower levels.

It was concluded that application of 100% NPK + FYM @50 t/ha to preceding potato along with rice residue incorporation resulted significantly higher yield

Table 2 Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on grain yield, stover yield and harvest index of spring maize

Treatment	Seed yield (q/ha)		Stover yield (q/ha)		Harvest index		Spring maize equivalent yield (q/ha)		System productivity (kg/ha/day)	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Rice residue and nutrient application to preceding potato										
M_1	76.7	79.5	150.0	158.1	0.33	0.33	249.8	259.6	81.1	87.2
M_2	72.4	72.9	142.8	150.9	0.33	0.32	226.9	236.0	74.1	78.4
M_3	80.1	83.6	154.0	164.3	0.34	0.34	257.6	267.4	82.9	89.1
M_4	75.5	76.6	148.4	155.5	0.33	0.33	232.9	244.7	74.5	80.8
LSD (P=0.05)	4.7	4.9	7.3	6.0	NS	NS	4.7	4.8	1.5	2.5
Nutrient levels in spring maize										
S_1	68.3	69.6	133.5	140.4	0.33	0.33	233.9	243.3	75.4	81.1
S_2	69.2	69.9	152.1	163.6	0.31	0.29	234.8	243.7	76.5	81.8
S_3	74.5	77.5	139.0	144.0	0.34	0.35	240.1	251.3	77.1	83.2
S_4	78.5	81.4	160.3	169.4	0.32	0.32	244.1	255.3	79.2	85.2
S_5	81.3	82.9	142.9	150.5	0.36	0.35	246.9	256.7	79.3	84.9
S_6	85.4	87.5	165.1	175.4	0.34	0.33	251.1	261.4	81.3	87.1
LSD (P=0.05)	3.1	3.8	7.7	9.5	0.02	0.02	3.0	3.8	1.1	1.3
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Treatment details are given under Materials and Methods.

Table 3 Effect of rice residue and nutrient application to preceding potato and nutrient levels to spring maize on economics of rice-potato-spring maize cropping system

Treatment	Gross returns ($\times 10^3$ ₹/ha)		Net returns ($\times 10^3$ ₹ha)		Benefit cost ratio		Profitability (₹/ha/day)	
	2019	2020	2019	2020	2019	2020	2019	2020
Rice residue and nutrient application to preceding potato								
M_1	439.7	485.0	247.2	286.7	1.28	1.45	677.4	785.4
M_2	399.3	441.3	215.4	251.7	1.17	1.33	590.0	689.5
M_3	453.3	499.6	259.9	300.2	1.34	1.51	712.2	822.5
M_4	409.8	457.5	224.8	266.9	1.22	1.40	616.0	731.2
Nutrient levels in spring maize								
S_1	411.6	454.9	225.4	262.9	1.21	1.37	617.6	720.3
S_2	413.2	455.6	224.7	261.3	1.19	1.34	615.5	715.9
S_3	422.5	469.7	235.4	276.8	1.26	1.43	644.9	758.5
S_4	429.6	477.0	240.2	281.7	1.27	1.44	658.1	771.9
S_5	434.5	479.6	245.2	284.5	1.29	1.46	671.9	779.5
S_6	441.8	488.2	250.2	290.8	1.30	1.47	685.4	796.9

Treatment details are given under Materials and Methods.

and yield attributes, system productivity and economics of spring maize in rice-potato-spring maize cropping system as compared to all the treatment combinations. Application of 125% NPK applied to double row bed planted spring maize recorded higher grain yield, stover yield, spring maize equivalent yield, system productivity and net returns during 2019 and 2020, respectively in comparison to 100% NPK applied to single row spring maize on bed.

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