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Production potential, economics and energetic as influenced by integrated nutrient management in soybean (*Glycine max*)–wheat (*Triticum aestivum*) cropping system

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ABSTRACT

The goal of a two-year field experiment at Indira Gandhi Krishi Vishwavidyalaya in Raipur, Chhattisgarh, in 2014–15 and 2015–16 was to assess the direct and residual effects of organic and inorganic fertilizers on the economics and productivity of a soybean–wheat cropping system (Glycine max (L.) Merill). In the main plots of the soybean experiment, four different nutrient sources were used: 5 t/ha of crop residues (wheat), RDF, 50% RDF, 5 kg/ha of zinc, and 2.5 t/ha of poultry manure. In the sub-plots, five different nutrient levels were used: F0, control, F1, 50% RDF, F2, RDF, F3, 50% RDF + Zn, and F4, RDF + Zn. Subplots for each of the five nutrient levels (F0, control; F1, 50% RDF; F2, RDF); F3, 50% RDF + Zn 5 kg/ha; and F4, RDF + Zn 5 kg/ha) were used to assess the residual impact of the nutrient sources applied to soybean in the main plots of wheat.

I see. A split-plot design with three crop replications was used to set up the experiment. Among the many nutrient sources tested, the results showed that soybean and wheat crops treated with poultry manure (2.5 t/ha) had the best grain and stover yields as well as economic characteristics (gross returns, net returns, and B:C ratio) when compared to the control and the other organic treatments. The soybean production had a higher cost of 20.2×10^{1}/ha owing to the wheat crop wastes, which weighed 5 t/ha. Among the many nutrient levels tested, the combination of RDF and 5 kg/ha of zinc resulted in the best economic metrics, stover yields, and grain yields. The optimal yearly application rates for chicken manure in soybeans and wheat, according to system yields and economic returns, are 2.5 t/ha for soybeans and RDF + 5 kg Zn/ha for both crops. This increases the productivity and profitability of the crops. To maximize production and profit while simultaneously improving soil fertility, it seems that a soybean-wheat cropping system that applies zinc, RDF, and chicken manure together is the best nutrient management choice.

Key words: Economics, Energetics, INM, Soybean–wheat cropping system, Yields

In India, the most common farming method is soybeans and wheat. Appropriate resource management, including balanced use of manures and fertilizers, is crucial to the viability of any agricultural system. Improved food grain output, more food self-sufficiency, and greater food security have all resulted from India's adoption of rice-wheat farming systems. Problems with sustainability and stagnant or falling crop output have put the rice-wheat production system in jeopardy. Traditional rice-wheat farming systems have significant issues since both grains are strong feeders and use up all the soil resources. In recent years, the soybean-wheat system has gained popularity as a viable option for crop diversification and for according to Verma and Sharma (2007), in order to keep the soils sustainable. Environmental contamination and physical, chemical, and biological soil deterioration result from using inorganic fertilizers without organic additives over an extended period of time. In addition to adding organic matter and nutrients, manures have a wide range of other effects on the soil, including changing its structure, influencing nutrient turnover, and increasing the size, diversity, and activity of the soil's microbial population (Albiach et al., 2000). With a protein content of 40–42% and an oil content of 20–22%, soybeans have quickly become one of India's most important oilseed crops. According to Anonymous (2014), the average global productivity of 2,670 kg/ha is far higher than the 1,162 kg/ha produced by India's soybean crop, which is grown on 10.84 million hectares. The country's total output is 14.67 million tons.

As one of the world's most significant cereal crops—and India's second-most important food crop, behind only rice—wheat plays a crucial role in guaranteeing the nation's food security. Its average productivity in 2015–16 was 2,272 kg/ha, and it covered an area of 30.96 million hectares, producing over 88.94 million tons (Anonymous, 2016). Food production, especially wheat, has increased in tandem with the fast rise in

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global population. Wheat yields an average of 1,455 kg/ha in Chhattisgarh. In Chhattisgarh, uneven fertilizer application or insufficient inorganic fertilizer use is the main reason for poor agricultural output.
Soil productivity has declined due to over-or under-applied chemical fertilizers used in intensive crop production; therefore, organic fertilizers should be added to chemical fertilizers to restore soil fertility and productivity (Behera et al., 2007). To keep the soil nutrient reserves for increased crop yields, it is possible to use chemical fertilizers in conjunction with bulky organics FYM, chicken manure, crop residues (wheat stover), and other sources of nutrients. chicken litter, an abundance of organic waste produced by Chhattisgarh's booming chicken sector, might find use in farming. Under these conditions, sustaining production, maintaining soil health, and improving nutrient-use efficiency may all be achieved via the integration and careful management of chemical and organic sources (Thakur et al. 2011). Therefore, in order to maximize crop output and profit, balanced nutrient administration is essential. Given the paucity of data on these factors in the soy-bean-wheat cropping system, researchers in the Chhattisgarh plains set out to fill that gap.

MATERIALS AND METHODS

During the 2014–15 and 2015–16 rainy and winter (kharif) seasons, researchers from the Indira Gandhi Krishi Vishwavidyalaya in Raipur, Chhattisgarh, carried out a field experiment at their research and instructional farm. The experimental field's clayey soil had a neutral pH of 6.9, an electrical conductivity of 0.13 ds/m, and a low organic carbon content of 0.46%. Soil fertility was marked as low for available nitrogen (214.2 kg/ha), medium for available phosphorus (21.50 kg/ha), and high for available potassium (319.2 kg/ha). The experimental design consisted of a split-plot layout with three replications. Soybean treatment included four nutritional sources: S, control; S,

also in the subplots, at 5 kg/ha of F4, RDF, and Zn. The major plots and nutrient levels were used to analyze the residual impact of nutrient sources supplied to soybean in the following wheat crop: 50% RDF (F1), RDF (F2), 50% RDF + Zn (5 kg/ha) (F3), and RDF + Zn (5 kg/ha) (F4). Applying

crop residues (wheat) 5 t/ha; S_2, FYM 5 t/ha; S_3, poultry manure 2.5 t/ha in the main plots and 5 nutrient levels; F_0, control; F_1, 50% RDF; F_2, RDF; F_3, 50% RDF + Zn 5 kg/

urea, single super phosphate, and muriate of potash as fertilizers to soybeans and wheat, respectively, should result in a 20:60:20 and 120:60:40 kg of N, P2O5, and K2O/ha dosage, respectively. The complete dosage of nitrogen, phosphorus, and potassium was administered to soybeans as a base. The wheat plants were treated with a full dosage of P2O5, half a dose of N at the basal stage, and half a dose of N at the maximum tillering and panicle initiation stages in two equal halves throughout the two years of the experiment.
The soybean variety 'JS 9752' and the wheat variety 'Ratan' were planted in rows 30 cm and 22.5 cm apart, respectively, with a seed rate of 80 and 120 kg/ha. The planting dates for soybeans and wheat were 17 July 2014 and 4 July 2015, respectively, and 14 November 2014 and 21 November 2015. Soybean crop seasons in 2014 and 2015 saw weekly average maximum and minimum temperatures ranging from 25.1oC to 33.4oC and 22.5oC to 28.3oC, respectively; wheat crop seasons in 2014 and 2015 saw temperatures ranging from 25oC to 33.5oC and 8oC to 19.3oC, and 2015 and 2016 saw temperatures ranging from 27oC to 35.4oC and 9oC to 20.8oC, respectively. For soybeans, the total rainfall from planting to harvest in 2014 was 868.0 mm, whereas for wheat it was 30.9 mm in 2014–15 and 46 mm in 2015–16. Over the course of the two experimental years, the wheat crop was irrigated four times in a consistent fashion. Nothing was changed to the original layout; the experiment took place on the same spot. Various treatments were used to record the grain and stover yields of soybeans and wheat from the net plot area, which were then translated into tonnes/ha. The cultivation cost and gross return (in metric tons) for each treatment were calculated using the current input and produce prices on the market. The cost of cultivation was deducted from the gross yields to get the net returns (/ha). To evaluate the treatments' monetary effects, we divided the gross returns by the cultivation costs and arrived at the B:C ratio. We used the provided formula to determine the system's total productivity in soybean-equivalent yield.

$$\text{SEY of wheat (t/ha)} = \frac{\text{Yield of wheat (t/ha)} \times \text{Price of wheat (₹/t)}}{\text{Price of soybean (₹/t)}}$$

The energy output of different treatments was calculated on the basis of biological yield as given by Mittal *et al.* (1985) and expressed as total energy (MJ/ha). Energy efficiency and output-input ratio were calculated by using the given formula.

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$$\text{Energy use efficiency (tMJ} \times 10^3) = \frac{\text{Total produce (Seed + Stover (in t)}}{\text{Energy input (MJ} \times 10^3)}$$

$$\text{Energy output-input ratio} = \frac{\text{Energy output}}{\text{Energy input (MK/ha)}}$$

The data collected from the experimental field and laboratory analysis was subjected to statistical analysis. Standard statistical methods were used (Gomez and Gomez., 1984). The results are presented at 5% level of significance (P=0.05) for making comparison between treatments.

RESULTS AND DISCUSSION

Grain and stover yield

The maximum grain (2.20 t/ha and 2.84 t/ha) and stover (4.27 t/ha and 6.0 t/ha) yields of both soybean and wheat were recorded with the application of direct and residual effect of poultry manure 2.5 t/ha (S_3), which was significantly higher than that of other treatment for both soybean and wheat crops (Table 1). The minimum grain and stover yields of both soybean and wheat crops were harvested from control (S_0) plot in 2 years mean data. Among the different nutrient levels, the highest grain (2.28 t/ha and 2.99 t/ha) and stover (4.30 t/ha and 6.14 t/ha) yields of soybean and wheat is obtained from the plots supplied with 100% RDF + Zn 5 kg/ha (F_4) and minimum under control (F_0) treatment. Rana and Badiyala (2014) also reported that the use of RDF resulted in significantly high seed (1.59 t/ha) and stover (3.14 t/ha) yields of soybean as compared to 50% RDF and the control. This was might be due to variation in variety of crops, soil and climatic conditions.

The nutrient sources and nutrient levels interacted significantly in terms of grain and stover yields of soybean as well as wheat crop. The direct and residual effect of poul-try manure (PM) 2.5 t/ha in combination with RDF + Zn 5 kg/ha (S_3F_4) recorded higher grain (2.48 t/ha and 3.39 t/ ha) and stover (4.63 t/ha 6.93 t/ha) yield of soybean and wheat crops. It was closely followed by the combination of FYM 5 t/ha × 100% RDF + Zn 5 kg/ha (S_2F_4) and PM 2.5 t/ha × 100% RDF (S_3F_2) for soybean crops and it was closely followed by the combination of FYM 5 t/ha × 100% RDF (S_2F_2) and PM 2.5 t/ha × 100% RDF (S_3F_2) in case of wheat. The lowest values of yield was observed in the combination of controls × control (S_0F_0) among the nutrient sources and nutrient levels in 2 years mean data of both soybean and wheat crops. Kumar *et al.* (2006) also reported higher yield of soybean due to combined application of nutrient sources, micronutrients and RDF by their complementary effect on soil bio-chemical reactions and soil fertility. Similar results have been reported by Shivakumar and Ahalawat (2008). Dwivedi and Thakur (2004) have recorded significantly higher yield attributes

Table 1. Grain and stover/straw yields, system productivity and soybean equivalent yield (SEY) as influenced by sources and levels of nutrients (mean data of 2 years)

Treatment		Yield (t/ha)				System productivity (t/ha)		Soybean equivalent yield (t/ha)
		Soybean		Wheat				
Soybean	Wheat	Grain	Stover	Grain	Straw	Grain	Stover	
Nutrient sources								
S_0, Control	S_0, Control	1.50	3.31	2.01	4.16	3.58	7.46	1.16
S_1, Crop residues 5 t/ha	S_1, Residual effect of previous treatment	1.86	3.63	2.38	5.01	4.24	8.64	1.37
S_2, FYM 5 t/ha	S_2, Residual effect of previous treatment	1.99	4.00	2.61	5.60	4.60	9.61	1.51
S_3, Poultry manure 2.5 t/ha	S_3, Residual effect of previous treatment	2.20	4.27	2.84	6.00	5.02	10.27	1.64
SEm±		0.11	0.37	0.14	0.15	0.22	0.39	0.08
CD (P=0.05)		0.39	1.27	0.50	0.53	0.77	1.36	0.29
Nutrient levels								
F_0, Control	F_0, Control	1.34	3.11	1.70	3.84	3.05	6.95	0.98
F_1, 50% RDF	F_1, 50% RDF	1.77	3.72	2.31	4.91	4.09	8.63	1.33
F_2, RDF	F_2, RDF	2.14	4.10	2.79	5.74	4.94	9.84	1.61
F_3, 50% RDF + Zn 5 kg/ha	F_3, 50% RDF + Zn 5 kg/ha	1.90	3.80	2.52	5.32	4.44	9.12	1.45
F_4, RDF + Zn 5 kg/ha	F_4, RDF + Zn 5 kg/ha	2.28	4.30	2.99	6.14	5.27	10.44	1.72
SEm±		0.21	0.40	0.22	0.41	0.41	0.63	0.13
CD (P=0.05)		0.62	1.17	0.63	1.17	1.17	1.82	0.36

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using the recommended fertilizer amount on wheat grown on FYM soil with residual fertility. Possible explanation: different therapy combinations can have this effect.

Efficiency as a whole

Using mean data spanning two years, researchers discovered that various nutrient sources affected the overall productivity of the soybean-wheat system. When compared to crops fertilized with other sources of nutrients, crops subjected to 2.5 t/ha of chicken manure showed much better production, with total grain yielding 5.02 t/ha and stover yielding 10.27 t/ha. The control plot, on the other hand, showed the lowest overall system production (Table 1).

In the two years of mean data, varying quantities of nutrients had a substantial impact on the overall productivity of the soybean-wheat cropping system. Results showed that soybean-wheat fertilized with RDF + Zn @ 5 kg/ha produced the best overall grain and stover yields (5.27 t/ha and 10.44 t/ha, respectively) compared to other nutrient levels (Table 1). When combined with the combined effects of 2.5 t/ha of direct and residual poultry manure, 5 kg of zinc per hectare (S3F4), and wheat, the soybean-wheat cropping system produced the highest total productivity in terms of total grain (5.85 t/ha) and stover (11.50 t/ha) yields compared to other treatment combinations. In the two-year mean data of soybean and wheat crops, the combination of controls and controls (S0F0) had the lowest values in all of these attributes pertaining to nutrient sources and levels.

Yield of soybeans (SEY)

In the two years of average data, the soybean equivalent yield (SEY) varied considerably between nutrient sources, with the maximum SEY of 1.64 t/ha recorded with the application of PM @ 2.5 t/ha (S3), which was much greater than the SEYs reported in other treatments. Among the two years of mean data, the control (S0) treatment had the lowest SEY. An increase in wheat production was the primary factor in the greater SEY output. The highest specific yield (SEY) of 1.72 t/ha was achieved when the crop was fertilized with 5 kg/ha of zinc and red dye (RDF) (F4). In contrast, the control group that did not receive any medication had the lowest SEY (Table 1).

In addition, when looking at the mean data from two years, the combined influence of nutrient sources and levels on soybean SEY was substantial. Evidence from the two years of mean data makes it clear that food sources, whether at the same or different quantities, dramatically changed the SEY. According to the two-year mean data, the maximum SEY of 1.95 t/ha was achieved with an application of 2.5 t/ha of PM in combination with RDF and 5 kg/ha of Zn (S3F4). This seems to be greater than the results obtained with alternative combinations of treatments. When compared to all other treatment combinations, the absolute control therapy (S0F0) had the lowest SEY (Table 1). The greatest equivalent yield was likewise recorded by Ramesh et al. (2009) in the soybean-wheat cropping system when integrated nutrient management was used.

Business and finance

The direct application of 2.5 t/ha of PM for soybeans and their subsequent wheat crops showed the best economics in terms of net return (40.8 × 10^1/ha and 31.3 × 10^2/ha) and B: C ratio (2.93 and 2.56) compared to other sources. This suggests that the residual effect greatly benefited the soybean crop. Poor grain and stover yields may explain why control plots had the lowest economic returns (Table 2).

In comparison to the control treatments that were not fertilized, the data also showed that economic returns rose as nutrient levels did. For both wheat and soybean crops, the application of RDF (F2) followed by fertilization with RDF + Zn 5 kg/ha (F4) had the largest net yields of 41.0 × 10^1 /ha and 31.3 × 10^2 /ha, respectively, with a wider B: C ratio of 2.79 and 2.41. Shivakumar and Ahlawat (2008) have observed similar findings. Conversely, the control plot (F0) treatment had the lowest economic returns.

The treatment combinations with the highest economic impacts in terms of net returns and B: C ratio were (S3F4), which consisted of PM @ 2.5 t/ha with RDF + Zn 5 kg/ha (Table 2), followed by (S3F2), according to the interaction effects among the various treatment combinations. The control-control (S0F0) treatment may have had the worst economic impact on soybean and wheat harvests out of all the treatment combinations. In conclusion, it was found that applying 2.5 t/ha of PM coupled with 5 kg/ha of RDF and Zn will assist achieve greater productivity and economic returns from both crops separately and from the soybean-wheat cropping system as a whole.

The power dynamics

Applying PM @ 2.5 t/ha (S3) to soybeans and their residual influence on the subsequent wheat crop resulted in the greatest total energy production of 32.33 and 116.65 MJ/ha, respectively, among the nutrient sources. This might be because both crops had the highest grain and stover yields. The control group that did not receive any therapy (S0) had the lowest energy output value. When comparing nutrient levels, the highest total energy production of soybeans (33.44 MJ/ha) and wheat (120.67 MJ/ha) were achieved with the application of RDF + Zn 5 kg/ha (F4).

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Table 2. Economics of soybean–wheat cropping system as influenced by sources and levels of nutrients (mean data of 2 years)

Treatment		Cost of cultivation ($\times 10^3$ ₹/ha)		Net returns ($\times 10^3$ ₹/ha)		Benefit : cost ratio	
Soybean	Wheat	Soybean	Wheat	Soybean	Wheat	Soybean	Wheat
Nutrient sources							
S_0, Control	S_0, Control	17.6	16.4	22.7	16.3	2.12	1.81
S_1, Crop residues 5 t/ha	S_1, Residual effect of previous treatment	20.2	16.4	29.7	23.0	2.30	2.14
S_2, FYM 5 t/ha	S_2, Residual effect of previous treatment	19.2	16.4	34.6	27.4	2.59	2.36
S_3, Poultry manure 2.5 t/ha	S_3, Residual effect of previous treatment	18.7	16.4	40.8	31.3	2.93	2.56
SEm±		–	0.06	0.37	0.01	0.01	
CD (P=0.05)		–	0.19	1.07	0.05	0.04	
Nutrient levels							
F_0, Control	F_0, Control	17.6	16.4	19.3	14.5	2.02	1.89
F_1, 50% RDF	F_1, 50% RDF	19.4	19.1	29.1	22.5	2.40	2.18
F_2, RDF	F_2, RDF	21.1	21.9	37.7	28.1	2.67	2.28
F_3, 50% RDF + Zn 5 kg/ha	F_3, 50% RDF + Zn 5 kg/ha	19.6	19.3	32.6	26.0	2.56	2.35
F_4, RDF + Zn 5 kg/ha	F_4, RDF + Zn 5 kg/ha	21.4	22.2	41.0	31.3	2.79	2.41
SEm±		–	–	0.30	0.78	0.03	0.02
CD (P=0.05)		–	–	0.92	2.31	0.08	0.05

MSP 2014–15: soybean ₹25,600/t, wheat ₹14,500; 2015–16 soybean ₹26,000/t, wheat ₹15,250/t

Table 3. Energy input and output relationship of soybean as influenced by sources and levels of nutrients (mean data of 2 years)

Treatment		Energy input (MJ $\times 10^3$)		Energy output (MJ/ha)		Energy output-input ratio		Energy-use efficiency (MJ $\times 10^3$/ha)	
Soybean	Wheat	Soybean	Wheat	Soybean	Wheat	Soybean	Wheat	Soybean	Wheat
Nutrient sources									
S_0, Control,	S_0, Control	4.55	3.93	22.02	81.54	4.84	20.73	1.06	1.57
S_1, Crop residues 5 t/ha	S_1, Residual effect of previous treatment	10.83	3.93	27.30	97.58	2.52	24.81	0.51	1.88
S_2, FYM 5 t/ha	S_2, Residual effect of previous treatment	6.08	3.93	29.28	108.38	4.82	27.55	0.99	2.09
S_3, Poultry manure 2.5 t/ha	S_3, Residual effect of previous treatment	7.33	3.93	32.33	116.65	4.41	29.66	0.88	2.25
Nutrient levels									0.00
F_0, Control	F_0, Control	4.55	3.93	19.74	72.95	4.34	18.54	0.98	1.41
F_1, 50% RDF	F_1, 50% RDF	5.56	8.02	25.96	95.33	4.67	11.89	0.99	0.90
F_2, RDF	F_2, RDF	6.56	12.10	31.50	112.69	4.80	9.31	0.95	0.71
F_3, 50% RDF + Zn 5 kg/ha	F_3, 50% RDF + Zn 5 kg/ha	6.61	9.06	27.99	103.54	4.23	11.43	0.86	0.87
F_4, RDF + Zn 5 kg/ha	F_4, RDF + Zn 5 kg/ha	7.61	13.14	33.44	120.67	4.39	9.18	0.86	0.70

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to the remainder of the therapies. According to Table 3, the control (F0) treatment resulted in the lowest overall energy production.

Because the total energy input was lower in the untreated control (S0) treatment compared to the nutrient applied treatment, the soybean energy output-input ratio was the greatest at 4.84. It is possible that the largest grain and stover yields compared to the other treatments were responsible for the residual impact of poultry manure @ 2.5 t/ha (S3) recording the highest energy output-input ratio (29.66) in the wheat crop. On

On the flip side, the energy output-input ratio was lowest in wheat when the control group did not receive any treatment (S) and soy beans when 5 t/ha of crop residues were applied (S).

1 0

The greatest value of the energy output-input ratio (4.80) of soybean was recorded after applying RDF (F2), which is relevant to nutritional levels. When comparing the different treatments, the untreated control (F0) group achieved the highest energy output-input ratio (18.54) in the subsequent wheat crop (Table 3). The energy output-input ratio of soybeans was found to be the lowest in the following wheat crops when 50% RDF + 5 kg/ha (F3) and RDF + 5 kg/ha (F4) were applied. This confirms what Billore and Joshi (2004) already found.

Because the total energy input was lower in the untreated control treatment compared to the nutrient administered treatment, the soybean crop achieved its greatest energy-use efficiency of 1.06 t MJ × 103/ha. It is possible that the maximum energy-use efficiency (2.25 t MJ × 103/ha) in the subsequent wheat crop was a result of the highest grain and stover yields, which occurred under the residual influence of applying PM @ 2.5 t/ha. Conversely, in a suc-ceeding wheat crop, the energy-use efficiency of soybeans was shown to be lowest when 5 t/ha of crop residues were applied, whereas the control treatment was left untreated.

Indeed, Billore and Joshi (2004) also found the same thing. The highest energy-use efficiency of soybean (0.99 t/MJ × 10^{1}3/ha) was seen when 50% RDF was applied, in relation to nutritional levels. It is possible that the lower total energy input relative to the fertilizer applied treatment is the reason why the untreated control treatment recorded the highest energy-use efficiency (1.41 t/MJ × 103/ha) in the subsequent wheat crop. According to Table 3, the energy-use efficiency of soybeans and wheat was found to be the lowest when treated with a combination of 50% RDF and 5 kg/ha of zinc.
The research found that when compared to other sources, the soybean-wheat cropping system with the direct and residual effects of chicken manure produced the greatest overall productivity net returns and B:C ratio. When fertilized with RDF + Zn @ 5 kg/ha, the two crops in the system had the best overall production, net returns, and B:C ratio compared to all other nutrient levels. The application of chicken manure in conjunction with RDF and 5 kg Zn/ha

resulted in the highest total productivity and profitability in comparison to their sole application.

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