Plant Archives Vol. 24, No. 2, 2024 pp. 2573-2581 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2024.v24.no.2.369

ENHANCING YIELD AND SUSTAINABILITY IN A MAIZE+MUNGBEAN-WHEAT CROPPING SEQUENCE THROUGH INTEGRATED NUTRIENT MANAGEMENT: A VIABLE ALTERNATIVE TO THE RICE-WHEAT SYSTEM

Aashu Rajput[1]*, Satendra Kumar[1], B.P. Dhyani[1], Yogesh Kumar[1], Adesh Singh[2] and Bhim Singh[3]

[1]Department of Soil Science, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut - 250 110, U.P., India.
[2]Department of Agronomy, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut - 250 110, U.P., India.
[3]Department of Statistics, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut - 250 110, U.P., India.
*Corresponding author E-mail : aashurajput.1997@gmail.com
(Date of Receiving-07-05-2024; Date of Acceptance-17-07-2024)

ABSTRACT

The rice-wheat cropping system (RWCS) dominates northwest India's agriculture due to favorable agro-climatic conditions, guaranteed minimum support prices and abundant irrigation. However, RWCS faces sustainability challenges due to resource depletion and environmental degradation. This study explores maize as an alternative to rice, owing to its lower water requirements and higher water productivity. Conducted at Sardar Vallabhbhai Patel University of Agriculture & Technology, the experiment employed a randomized block design with eleven treatments, including various combinations of inorganic and organic nutrient management practices. Maize, mungbean, and wheat were sown and analyzed for grain yield, stover yield, and biological yield. Results showed significant yield improvements in treatments integrating organic amendments (*e.g.*, poultry manure, Beejamrit and Jeevamrit) with recommended fertilizers. The highest yields were observed in the T_{10} treatment (100% RDF + 25% N from PM + Beejamrit ST + Jeevamrit spray), highlighting the synergistic effects of organic and inorganic nutrient sources. This integrated approach not only enhances crop yields, but also improves soil health, suggesting a viable strategy for sustainable agriculture in northwest India.

Key words : Integrated Nutrient Management (INM), Rice-Wheat Cropping System (RWCS), Sustainable Agriculture, Maize-Wheat System, Organic Amendments.

Introduction

Due to ideal agro-climatic conditions, ecological compatibility and the availability of natural resources, northwest India is home to the largest agricultural output cropping system in the world, the rice-wheat cropping system (RWCS). Additionally, low-cost irrigation services, guaranteed purchases at a minimal support price, and easy access to machinery for sowing and harvesting activities all help the implementation of RWCS in northwest India. This system supports a significant portion of the nation's food security and provides jobs for millions of rural residents. The RWCS is widespread throughout the states, particularly in Punjab, Haryana, and Uttar Pradesh, and the majority of these areas rely on groundwater for agriculture (Ambast *et al*., 2006).

The advent of the Green Revolution led to a substantial increase in foodgrain output through technical interventions. However, current farming techniques in the RWCS are eroding soil and water resources, jeopardizing the system's sustainability (Chauhan *et al*., 2012; Kumar *et al*., 2018). Crop productivity has risen in the past decade, but at the cost of improper input management, which negatively impacts the ecosystem, biodiversity, soil quality, and air quality (Tilman *et al*., 2011; Godfray and Garnett, 2014). Agriculture accounts for about 16% of India's greenhouse gas emissions, with methane emissions from rice and cattle contributing significantly (Vetter *et al*., 2017). The puddling technique used in rice farming destroys soil structure, resulting in poor aeration and compaction (Pathak *et al*., 2011). This creates a hardpan at shallow depths, inhibiting root growth for subsequent wheat crops. Excessive groundwater use and poor management have drastically lowered the groundwater table (Humphreys and Gaydon, 2015). Exhaustive cereal crops like rice and wheat significantly deplete soil nutrients, and the situation worsens when farmers burn rice crop residues after mechanical harvesting. Residue burning is a widespread practice in northwest and parts of eastern India, leading to severe air pollution (NAAS, 2017).

Given these challenges, there is an urgent need for sustainable alternatives that conserve water, maintain soil health and ensure environmental safety. Maize offers a promising substitute for puddled transplanted rice due to several advantages (Dhanda *et al*., 2022). Maize requires 80–85% less water than rice and has 8–22 times higher water productivity (Bouman, 2009; Gathala *et al*., 2013). The maize-wheat system also shows improved soil health and higher microbiological and enzymatic activity compared to the RWCS (Jat *et al*., 2012; Wei *et al*., 2015).

Maize (*Zea mays* L.), the second most widely grown crop globally, is highly adaptable to various climatic conditions, from tropics and sub-tropics to temperate regions. It can be cultivated from sea level up to 3000 m above mean sea level. Approximately 1060 million tonnes of maize are produced worldwide from an area of 188 million hectares, with an average productivity of 5.75 tonnes per hectare (IIMR, 2021). In India, maize is grown over 9.2 million hectares, producing 31.51 million tonnes, with Karnataka, Madhya Pradesh, Maharashtra, Rajasthan and Uttar Pradesh being the leading maize-producing states (Directorate of Economics and Statistics, 2021). However, maize is a resource-intensive crop that rapidly depletes soil nutrients, particularly nitrogen, which is crucial for maize development (Amanullah *et al*., 2008). The amount of nitrogen required depends on soil type, climate, genotypes and agronomic practices. Proper nitrogen management enhances plant growth, grain quality, and protein content (Leghari *et al*., 2016). Since nitrogen is often lost through leaching and denitrification during the kharif season, applying N fertilizer at the right time and in split doses can improve nutrient uptake and prevent losses (Gehl *et al*., 2005; Sitthaphanit *et al*., 2010).

Green gram (*Vigna radiata*), also known as mung bean, is a legume that plays a crucial role in restoring soil fertility through nitrogen fixation in symbiosis with Rhizobium bacteria. India, the largest producer of green gram, cultivates it on roughly 4.5 million hectares, producing 2.64 million tonnes (Greengram Outlook Report, 2021). Legumes improve soil fertility and crop yield, making them a key component of Integrated Nutrient Management (INM) (Yadav *et al*., 2000; Meena *et al*., 2015).

The current global situation emphasizes the need for eco-friendly farming practices to achieve sustainable food production. Conventional farming without organic manure depletes soil fertility and contributes to global warming (Schjonning *et al*., 2002). Organic liquid manures like beejamrit, jeevamrit and panchagavya, made from cow dung, urine, milk, curd, ghee, legume flour, and jaggery, enhance soil microbial activity and crop growth (Natarajan, 2007; Palekar, 2006; Sreenivasa *et al*., 2010). These organic solutions promote nutrient availability and improve soil health, leading to better crop productivity (Bhavalkar, 1991; Ismail *et al*., 1998). Poultry manure, when properly composted, is another effective organic fertilizer. It improves soil fertility by increasing pH, organic matter, total nitrogen, available phosphorus, exchangeable cations, cation exchange capacity, and base saturation (Adeleye, 2010). Combining organic manures with mineral fertilizers enhances enzymatic activities and plant biomass, contributing to sustainable crop productivity (Samuel *et al*., 2018; Patel *et al*., 2020).

Wheat (*Triticum aestivum* L.), a major cereal crop, is vital for food and nutrition security. In 2020–21, India's wheat production reached 108.75 million tonnes with an average productivity of 3424 kg/ha (Directorate of Economics and Statistics, Ministry of Agriculture and Farmers' Welfare). Wheat management practices such as residue management, optimal seed rate, and reduced tillage enhance soil structure and water retention, leading to improved yields (Plaza-Bonilla *et al*., 2013). For sustainable yields and better soil health, balanced fertilization in maize-wheat cropping systems should incorporate chemical, organic and bio-fertilizers as part of INM (Kemal and Abera, 2015). Introducing grain legumes to cereal-based cropping systems increases productivity and profitability, contributing to food security and sustainability (Swaminathan, 1998; Zhu *et al*., 2000). Although intercropping pulses with maize has shown benefits, further research is needed to understand its impact on subsequent crops in the system. Given these considerations, an experiment was conducted with the objective of enhancing yield, ultimately maximizing farmers' income, and promoting the Maize+Mungbean-Wheat cropping sequence as a viable alternative to the traditional Rice-Wheat system.

Materials and Methods

The study was conducted during the *Kharif* and *Rabi* seasons of 2022 and 2023 at the Crop Research Centre

(C.R.C.) of Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, Uttar Pradesh, India. The experiment employed a randomized block design (RBD) with three replications and eleven treatments. The treatments included various nutrient management practices involving inorganic and organic sources, 100% RDF (Control) (T_1); 100% RDF + Beejamrit seed treatment (T_2); 100% RDF + Jeevamrit spray (at sowing and 30 DAS) (T_3); 100% RDF + Beejamrit seed treatment + Jeevamrit spray (at sowing and 30 DAS) (T_4); 75% RDF + 25% N from Poultry manure + Jeevamrit spray (at sowing and 30 DAS) (T_5); 75% RDF + 25% N from Poultry manure + Beejamrit seed treatment (T_6); 75% RDF + 25% N from Poultry manure + Beejamrit seed treatment + Jeevamrit spray (at sowing and 30 DAS) (T_7); 100% RDF + 25% N from Poultry manure + Beejamrit seed treatment (T_8); 100% RDF + 25% N from Poultry manure + Jeevamrit spray (at sowing and 30 DAS) (T_9); 100% RDF + 25% N from Poultry manure + Beejamrit seed treatment + Jeevamrit spray (at sowing and 30 DAS) (T_{10}) and 125% RDF (T_{11}). The crops studied were maize (*Zea mays* L.), mungbean (*Vigna radiata* L.) and wheat (*Triticum aestivum* L.), with varieties Sujata and Samrat and PBW 343, respectively.

Composite soil sample of 0-15cm soil depth will be taken with the help of auger at sowing and parameters will be recorded given in Table A.

The maize and mungbean were sown on June 28, 2022. The experimental site featured appropriate field and plot borders and irrigation channels to ensure proper water management. Seed rates were 25 kg/ha for maize and mungbean and 100 kg/ha for wheat.After Rabi crop harvest, pre-sowing irrigation and one disc ploughing followed by two cultivator ploughings with planking were conducted. Fertilizers were applied at 120 kg N, 60 kg P_2O_5 and 60 kg K_2O ha^{-1} for maize, with half the nitrogen and all phosphorus and potassium as a basal dose at sowing. Each plot measured 5.0 m x 4.8 m, with spacing of 60x20 cm for maize, 30x10 cm for mungbean. Gap filling for maize was done after 5-7 days and thinning for mungbean at 15-20 days. Irrigation and weed management were performed as needed, with hand weeding at 25 DAS. Harvesting was done manually, with separate collection for each net plot. For wheat crop, the experimental plot was prepared separately as mungbean residue was incorporated with one deep ploughing followed by two cross-disc harrowings and leveling. Fertilizers (N:P:K @ 150:60:40 kg/ha) were applied, with half of the nitrogen and full phosphorus as basal dose, and the remaining nitrogen top-dressed at first irrigation. Wheat seeds were sown at 5 cm depth in furrows spaced at 22.5 cm. Irrigation was applied as needed, with manual weeding at 25 and 40 days after planting. Harvesting involved cutting, drying, and weighing the bundles, followed by manual threshing and winnowing.All the experimental data were statistically analysed by the analysis of variance (ANOVA). The significance of treatment effects will be computed with the help of 'F' (Variation ratio) test and to judge the significance of difference between means of two treatments, critical difference (CD) will be worked out as described by Gomez and Gomez (1984).

Maize stover yield will be measured by cutting plants above the soil surface after cob harvest and weighing them on a hectare basis. Biological yield will be determined by adding stover and cobs with husk yield from each plot, reported as kg/ha. Grain yield will be obtained by harvesting cobs from each net plot, separating grains and weighing them at 14% moisture content, reported in kg/ha. For mungbean, grain yield will be measured by threshing, winnowing and weighing grains from each net plot, converted to q/ha. Straw yield will be calculated by subtracting grain yield from biological yield. For wheat, grain yield will be recorded post-threshing and winnowing, and straw yield will be obtained by subtracting grain yield from biological yield, both expressed as q/ha. Biological yield for all crops will include above-ground biomass, dried and weighed.

Table A :

Observations	Initial Values		Instrument/ Method
	Ist year	IInd year	
pH	7.51	7.35	pH meter (Jackson,1973) in ratio 1:2 soil: water ratio
EC (dS/m)	0.113	0.115	Conductivity meter (Bover and Wilcox, 1965) in 1:2 soil: water
Organic carbon(%)	0.426	0.386	Modified Walkley and Black method (Walkley and Black, 1934)
Nitrogen (kg/ha)	231.45	171.87	By using alkaline $KMnO_4$ method (Subbiah and Asija,1956)
Phosphorus (kg/ha)	31.86	25.24	By using 0.5M $NaHCO_3$ having 8.5 pH (Olsen *et al.*, 1954)
Potassium (kg/ha)	215.17	190.65	1N NH_4OAC extraction by flame photometer (Black, 1965)
Soil moisture	75.6%	70.25%	Gravimetric method (Jackson,1973)

Results and Discussion

The data from research on maize yield across different nutrient management treatments provides valuable insights into the effectiveness of integrated nutrient management (INM) strategies.

Interpreting the results from Table 1, Fig. 1 and discussing the significant percentage variations between the highest and lowest treatments for grain yield, stover yield and biological yield for mung bean. The grain yield varied significantly among different treatments across the two years. The lowest yield was observed in the T_{11} treatment (125% RDF) with 3.90 t/ha in 2022-2023 and 3.92 t/ha in 2023-2024. The highest yield was recorded in the T_{10} treatment (100% RDF + 25% N from PM + Beejamrit ST + Jeevamrit spray) with 5.18 t/ha in 2022-2023 and 5.19 t/ha in 2023-2024. This represents an increase of approximately 32.82% and 32.40% respectively compared to the T_{11} treatment. The significant increase in grain yield in T_{10} can be attributed to the combined benefits of organic inputs (PM, Beejamrit and Jeevamrit) along with the recommended dose of fertilizers (RDF). Previous studies have shown that the integration of organic and inorganic nutrient sources can enhance nutrient availability, improve soil health, and subsequently increase crop yield (Sharma *et al.*, 2022).

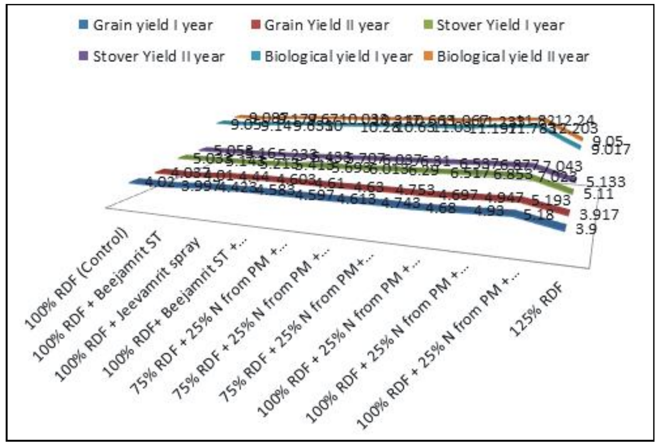

Fig. 1 : Influence of INM practices on yield(t/ha) of maize crop.

Stover yield also showed a substantial increase with the highest yield in T_{10} (7.02 t/ha in 2022-2023 and 7.04

Table 1 : Impact of INM practices on maize yield under maize+mungbean-wheat cropping sequence.

Maize	Grain yield		Straw Yield		Biological Yield	
Treatments	**2022-2023**	**2023-2024**	**2022-2023**	**2023-2024**	**2022-2023**	**2023-2024**
T_1: 100% RDF (Control)	4.02	4.04	5.03	5.05	9.05	9.09
T_2: 100% RDF + Beejamrit ST	4.00	4.01	5.14	5.16	9.14	9.18
T_3: 100% RDF + Jeevamrit spray	4.42	4.44	5.21	5.23	9.63	9.67
T_4: 100% RDF+ Beejamrit ST + Jeevamrit spray	4.58	4.60	5.41	5.43	10.00	10.03
T_5: 75% RDF + 25% N from PM + Jeevamrit spray	4.60	4.61	5.69	5.71	10.28	10.32
T_6: 75% RDF + 25% N from PM + Beejamrit ST	4.61	4.63	6.01	6.04	10.63	10.66
T_7: 75% RDF + 25% N from PM+ Beejamrit ST + Jeevamrit spray	4.74	4.75	6.29	6.31	11.03	11.07
T_8: 100% RDF + 25% N from PM + Beejamrit ST	4.68	4.70	6.52	6.54	11.20	11.23
T_9: 100% RDF + 25% N from PM + Jeevamrit spray	4.93	4.95	6.85	6.88	11.78	11.82
T_{10}: 100% RDF + 25% N from PM + Beejamrit ST + Jeevamrit spray	5.18	5.19	7.02	7.04	12.20	12.24
T_{11}: 125% RDF	3.90	3.92	5.11	5.13	9.02	9.05
C.D.	0.178	0.188	0.288	0.189	0.288	0.236
SE (m)	0.06	0.063	0.097	0.064	0.097	0.079
SE (d)	0.085	0.09	0.137	0.09	0.137	0.112
C.V.	2.296	2.423	2.869	1.875	1.621	1.321

t/ha in 2023-2024) compared to the lowest yield in T_1 (100% RDF) with 5.03 t/ha in 2022-2023 and 5.05 t/ha in 2023-2024. This indicates a 39.56% increase in stover yield for 2022-2023 and 39.41% for 2023-2024. The increase in stover yield is consistent with the findings of Kumar *et al*. (2021), who reported that the application of organic manures along with chemical fertilizers enhances biomass production. The microbial activity stimulated by organic amendments improves nutrient cycling and plant growth.

The biological yield, which is the sum of grain and stover yield, showed the highest values in T_{10} with 12.20 t/ha in 2022-2023 and 12.24 t/ha in 2023-2024. The lowest biological yield was observed in T_1 with 9.05 t/ha in 2022-2023 and 9.09 t/ha in 2023-2024. This translates to an increase of approximately 34.92% for both years. Biological yield is a crucial indicator of the overall productivity of a crop. The substantial increase in biological yield in the T_{10} treatment can be attributed to the synergistic effects of organic and inorganic nutrient sources, which improve soil structure, enhance microbial activity, and increase nutrient availability (Patel *et al*., 2023). Integrated nutrient management practices have been shown to improve soil health, nutrient availability, and microbial activity, leading to better crop performance (Dhaliwal *et al*., 2021 and Paramesh *et al*., 2023). Ramesh *et al*. (2023) highlighted that combining RDF with organic amendments like vermicompost significantly improved maize yield and growth parameters. Similarly, studies have shown that the application of INM not only boosts crop yield but also enhances soil properties such as organic carbon content, nutrient status and microbial biomass.

Mungbean

The grain yield of mungbean varied significantly across treatments (Table 2 and Fig. 2). The highest grain yield was observed in T_{10} (100% RDF + 25% N from PM + Beejamrit ST + Jeevamrit spray) with 10.15 and 11.17 quintals per hectare in 2022-2023 and 2023-2024, respectively. The lowest yield was recorded in T11 (125% RDF) with 6.20 and 7.22 quintals per hectare. This indicates a substantial increase of approximately 63.7%

Table 2 : Effect of INM practices on Mungbean yield under maize+mungbean-wheat cropping sequence.

Mungbean	Grain yield		Straw Yield		Biological Yield	
Treatments	**2022-2023**	**2023-2024**	**2022-2023**	**2023-2024**	**2022-2023**	**2023-2024**
T_1: 100% RDF (Control)	6.60	7.62	17.73	17.84	24.33	25.45
T_2: 100% RDF + Beejamrit ST	7.15	8.17	17.98	18.25	25.13	26.42
T_3: 100% RDF + Jeevamrit spray	7.90	8.92	18.40	18.59	26.30	27.51
T_4: 100% RDF+ Beejamrit ST + Jeevamrit spray	8.00	9.02	18.74	18.69	26.74	27.70
T_5: 75% RDF + 25% N from PM + Jeevamrit spray	8.50	9.52	18.83	18.84	27.33	28.37
T_6: 75% RDF + 25% N from PM + Beejamrit ST	9.00	10.02	19.00	19.36	27.99	29.38
T_7: 75% RDF + 25% N from PM+ Beejamrit ST + Jeevamrit spray	9.45	10.47	19.51	19.93	28.96	30.40
T_8: 100% RDF + 25% N from PM + Beejamrit ST	9.90	10.92	20.08	20.69	29.98	31.61
T_9: 100% RDF + 25% N from PM + Jeevamrit spray	10.00	11.02	20.84	21.14	30.84	32.16
T_{10}: 100% RDF + 25% N from PM + Beejamrit ST + Jeevamrit spray	10.15	11.17	21.29	17.64	31.44	28.81
T_{11}: 125% RDF	6.20	7.22	17.79	17.54	23.99	24.76
C.D.	0.396	0.44	0.619	0.613	0.707	0.891
SE(m)	0.133	0.148	0.209	0.206	0.238	0.3
SE (d)	0.188	0.21	0.295	0.292	0.336	0.424
C.V.	2.734	2.713	1.89	1.885	1.495	1.829

and 54.7% in grain yield with the highest treatment compared to the lowest. Stover yield also showed significant variation, with the highest recorded in T_{10} with 21.29 and 17.64 quintals per hectare, respectively, for 2022-2023 and 2023-2024. The lowest was observed in T_1 (100% RDF - Control) with 17.73 and 17.84 quintals per hectare. This represents an increase of 20.0% and a slight decrease in 2023-2024, respectively. The biological yield, which combines both grain and stover yield was highest in T_{10} with 31.44 and 28.81 quintals per hectare for 2022-2023 and 2023-2024. The lowest was recorded in T_{11} with 23.99 and 24.76 quintals per hectare. This indicates an increase of approximately 31.0% and 16.3%, respectively.

The grain yield improvement observed with the integrated treatments aligns with findings by Patel *et al.* (2023), who reported that combining chemical fertilizers with organic amendments significantly boosts legume crop yields. The increased yield in T_{10} could be due to enhanced nitrogen fixation and better nutrient uptake facilitated by the organic amendments. The variations in stover yield highlight the positive impact of organic amendments on biomass production. According to Sharma *et al.* (2022), the application of organic manures, such as PM, along with bio-enhancers like Jeevamrit, leads to higher biomass accumulation due to improved soil structure and moisture retention. The overall biological yield improvements reflect the cumulative benefits of the integrated nutrient management practices. The synergy between chemical and organic fertilizers not only increases the nutrient availability, but also enhances soil fertility and plant health, leading to higher total biomass production (Kumar *et al.*, 2023). The significant increase in grain, stover, and biological yields of mungbean with the integrated use of RDF, PM, Beejamrit and Jeevamrit can be attributed to the combined benefits of chemical and organic fertilizers. Recent studies have shown that the application of organic amendments such as Jeevamrit and Beejamrit improves soil microbial activity, nutrient availability, and overall soil health (Rathore *et al.*, 2022). These organic treatments provide a slow and steady release of nutrients, enhancing plant growth and yield (Singh and Singh, 2021).

Wheat

Here's an interpretation of the results from the Table 3 and Fig. 3. The grain yield of wheat varied significantly across different treatments. The control treatment (T1) with 100% RDF recorded a yield of 46.00 q/ha in 2022-2023 and 48.37 q/ha in 2023-2024. The highest grain yield was observed in treatment T_{10} (100% RDF + 25% N from PM + Beejamrit ST + Jeevamrit spray), with yields of 54.55 q/ha and 56.92 q/ha for the respective years. This indicates a significant improvement over the control by 18.6% in 2022-2023 and 17.7% in 2023-2024. Recent studies corroborate these findings, showing that the integration of organic and inorganic fertilizers enhances nutrient availability and improves crop yields (Sharma *et al.*, 2020). The addition of Jeevamrit and Beejamrit appears to have a synergistic effect, possibly due to enhanced microbial activity and better nutrient mobilization (Meena *et al.*, 2021). The stover yield for wheat also showed significant variation among treatments. The control (T_1) yielded 37.65 q/ha in 2022-2023 and 36.33 q/ha in 2023-2024. Treatment T_8 (100% RDF + 25% N from PM + Beejamrit ST) yielded the highest stover, with 41.35 q/ha and 39.56 q/ha for the two years, respectively. This is an increase of approximately 9.8% in 2022-2023 and 8.9% in 2023-2024 compared to the control. Enhanced stover yield with organic amendments is supported by previous research, which attributes the increase to improved soil structure and moisture retention (Kumar *et al.*, 2019). The presence of organic matter from PM (Poultry Manure) and bio-enhancers like Beejamrit may contribute to better plant growth and biomass accumulation (Singh *et al.*, 2020). The biological yield, which includes both grain and stover yield, showed similar

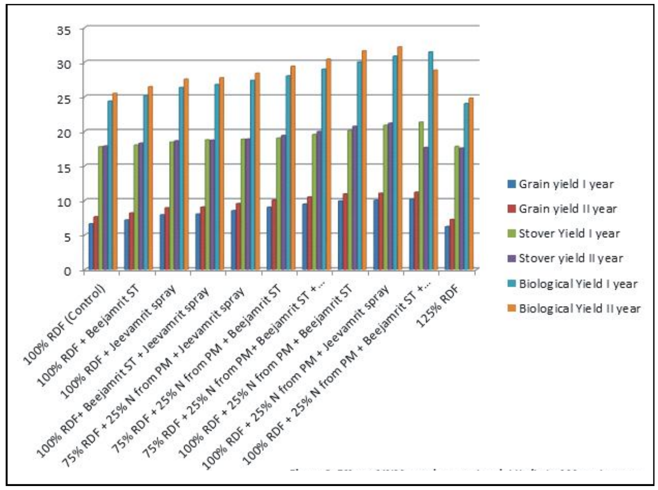

Fig. 2 : Effect of INM practices on the yield(q/ha) of Mung bean crop.

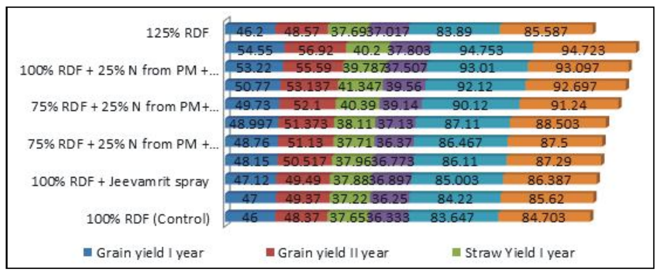

Fig. 3 : Impact of INM on wheat yield (q/ha).

Table 3 : Impact of INM practices on wheat yield under maize+mungbean-wheat cropping sequence.

Wheat	**Grain Yield**		**Straw Yield**		**Biological Yield**	
Treatments	**2022-2023**	**2023-2024**	**2022-2023**	**2023-2024**	**2022-2023**	**2023-2024**
T_1: 100% RDF (Control)	46.00	48.37	37.65	36.33	83.65	84.70
T_2: 100% RDF + Beejamrit ST	47.00	49.37	37.22	36.25	84.22	85.62
T_3: 100% RDF + Jeevamrit spray	47.12	49.49	37.88	36.90	85.00	86.39
T_4: 100% RDF+ Beejamrit ST + Jeevamrit spray	48.15	50.52	37.96	36.77	86.11	87.29
T_5: 75% RDF + 25% N from PM + Jeevamrit spray	48.76	51.13	37.71	36.37	86.47	87.50
T_6: 75% RDF + 25% N from PM + Beejamrit ST	49.00	51.37	38.11	37.13	87.11	88.50
T_7: 75% RDF + 25% N from PM+ Beejamrit ST + Jeevamrit spray	49.73	52.10	40.39	39.14	90.12	91.24
T_8: 100% RDF + 25% N from PM + Beejamrit ST	50.77	53.14	41.35	39.56	92.12	92.70
T_9: 100% RDF + 25% N from PM + Jeevamrit spray	53.22	55.59	39.79	37.51	93.01	93.10
T_{10}: 100% RDF + 25% N from PM + Beejamrit ST + Jeevamrit spray	54.55	56.92	40.20	37.80	94.75	94.72
T_{11}: 125% RDF	46.20	48.57	37.69	37.02	83.89	85.59
C.D.	2.121	2.25	N/A	2.05	3.43	0.80
SE (m)	0.714	0.757	1.51	0.69	1.15	0.27
SE (d)	1.01	1.071	2.14	0.98	1.63	0.38
C.V.	2.517	2.547	6.77	3.20	2.27	0.53

trends. The control treatment recorded yields of 83.65 q/ha in 2022-2023 and 84.70 q/ha in 2023-2024. Treatment T10 again outperformed other treatments, yielding 94.75 q/ha in 2022-2023 and 94.72 q/ha in 2023-2024. This represents a 13.3% increase in 2022-2023 and an 11.8% increase in 2023-2024 over the control. These results are consistent with findings by Patel *et al*. (2022), who reported that the combined use of organic and inorganic fertilizers can significantly enhance the biological yield of crops by improving overall plant health and productivity. Integrated Nutrient Management (INM), which emphasizes the balanced use of organic and inorganic fertilizers to optimize crop yields of wheat and maintain soil health (Bhattacharyya *et al*., 2021). The use of bio-enhancers like Jeevamrit and Beejamrit not only improves nutrient availability but also promotes microbial activity, leading to better nutrient uptake and utilization by plants (Yadav *et al*., 2020).

Conclusion

The findings of this research demonstrate the efficacy of the Maize+Mungbean-Wheat cropping sequence as a sustainable alternative to the traditional Rice-Wheat Cropping System (RWCS). This cropping sequence not only addresses the environmental concerns associated with RWCS, such as water depletion, soil degradation and air pollution from residue burning, but also offers aviable alternative that conserves water and enhances soil fertility. The adoption of the Maize+Mungbean-Wheat system, supported by appropriate INM a sustainable pathway to achieving higher crop yields, improved soil health, and reduced environmental impact, there by promoting agricultural sustainability in north west India. Integrated Nutrient Management (INM) practices, particularly the combination of 100% RDF with 25% nitrogen from poultry manure and the use of bio-enhancers like Beejamrit and Jeevamrit have shown substantial improvements in crop yields and soil health. The improved performance of the Maize+Mungbean-Wheat system can be attributed to enhanced nutrient availability, better soil structure and increased microbial activity due to the integrated use of organic amendments. These results align with previous studies highlighting the positive impacts of

INM on crop productivity and soil health.

Acknowledgement

I extend my heartfelt gratitude to the Department of Soil Science and Agricultural Chemistry at Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, for providing the facilities and support necessary for this research. I am particularly grateful to Dr. Satendra Kumar, whose invaluable guidance and encouragement were instrumental in the completion of this study. I also appreciate the assistance of the faculty, staff, and my fellow researchers, whose contributions and camaraderie greatly enriched this work. Finally, I thank my family and friends for their unwavering support throughout this journey.

References

Adeleye, E.O., Ayeni L.S. and Ojeniyi S.O. (2010). Effect of poultry manure on soil physico-chemical properties, leaf nutrient contents and yield of yam (*Dioscorea rotundata*) on Alfisol in southwestern Nigeria. *Am. J. Sci.,* **6(10)**, 871-878.

Amanullah, M.M., Sekar S. and Vincent S. (2008). Nitrogen use efficiency in maize. *Agric. Rev*., **29(2)**, 149-154.

Ambast, S.K., Tyagi N.K. and Raul S.K. (2006). Management of declining groundwater in the Trans Indo-Gangetic Plain (India): some options. *Agric. Water Manag*., **82**, 279–296.

Asija, S., Subbiah B.V. and Asija G.L. (1956). Rapid procedure for the estimation of the available nitrogen in soils. *Curr. Sci*., **25**, 259-260.

Bhattacharyya, R., Kundu S. and Pramanik P. (2021). Integrated Nutrient Management for Sustainable Agriculture: An Indian Scenario. *J. Soil Sci. Plant Nutr*., **21(1)**, 1-23.

Bhavalkar, U. (1991). *Panchagavya: a manual*. Institute of Natural Organic Agriculture, Pune, India.

Black, C.A. (1965). *Methods of Soil Analysis*. Part 2. Chemical and Microbiological.

Bouman, B.A.M. (2009). How much water does rice use? *Rice Today*, **8(1)**, 28-29.

Bover, C.A. and Wilcox L.A. (1965). Soluble salts. In: *Meth. of S. Analy. Chem. & Microbio. Prop. Monog*., 9. ASA and SSSA, Madison, Wisconsin, USA.443-451.

Chauhan, B.S., Mahajan G., Sardana V., Timsina J. and Jat M.L. (2012). Productivity and sustainability of the rice–wheat cropping system in the Indo-Gangetic Plains of the Indian subcontinent: problems, opportunities and strategies. *Adv. Agron.*, **117**, 315–369.

Dhaliwal, S.S., Sharma S., Sharma V., Shukla A.K., Walia S.S., Alhomrani M., Gaber A., Toor A.S., Verma V., Randhawa M.K. and Pandher L.K. (2021). Long-term integrated nutrient management in the maize–wheat cropping system in alluvial soils of North-Western India: Influence on soil organic carbon, microbial activity and nutrient status. *Agron.*, **11(11)**, 2258.

Dhanda, R.S., Kaur G. and Singh K. (2022). Resource conservation technologies for sustainable production of maize-wheat cropping system in Punjab, India. *Agric. Rev*., **43(2)**, 140-150.

Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare (2021). Annual Report 2020-21.

Directorate of Economics and Statistics (2021). 4th Advance Estimates of Production of Foodgrains for 2020-21. Ministry of Agriculture and Farmers Welfare, Government of India.

Gathala, M.K., Ladha J.K., Kumar V., Saharawat Y.S., Kumar V. and Sharma P.K. (2013). Tillage and crop establishment affects sustainability of South Asian rice-wheat system. *J. Agron*., **105(2)**, 527-538.

Gehl, R.J., Schmidt J.P., Maddux L.D. and Gordon W.B. (2005). Corn yield response to nitrogen rate and timing in sandy irrigated soils. *J. Agro*., **97(4)**, 1230-1238.

Godfray, H.C.J. and Garnett T. (2014). Food security and sustainable intensification. *Phil. Trans. R. Soc*., *B* **369**, 20120273.

Gomez, K.A. and Gomez A.A. (1984). *Statistical procedures for agricultural research*. Edition 2, John Willy, New York, pp. 693.

Greengram Outlook Report (2021). January to May 2021. Published by Agricultural Market Intelligence Centre, PJTSAU.

Humphreys, E. and Gaydon D.S. (2015). Options for increasing the productivity of the rice–wheat system of north-west India while reducing groundwater depletion. Part 2. Is conservation agriculture the answer? *Field Crops Res*., **173**, 81–94.

IIMR (2021). *Annual Report 2020-21*. Indian Institute of Maize Research. Ludhiana, India.

Ismail, S.A., Venkatesan S. and Dhanapal R. (1998). Studies on the effect of organic amendments and bio-fertilizers on growth and yield of crops. *J. Karn. Agric. Sci*., **11(2)**, 365-370.

Jackson, M.L. (1973). *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd., second Indian Reprint, New Delhi, India.

Jat, M.L., Saharawat Y.S. and Gupta R. (2012). Conservation agriculture in cereal systems of South Asia: Nutrient management perspectives. *J. Karn. Agri. Sci*., **25(2)**, 129-136.

Kemal, W. and Abera T. (2015). Integrated nutrient management for maize (*Zea mays* L.) production in acidic soil of southwestern Ethiopia. *JAST*, **17(5)**, 1613-1625.

Kumar, S., Singh R. and Meena R.S. (2021). Effect of Integrated Nutrient Management on Growth, Yield and Quality of Maize (*Zea mays* L.). *J. Plant Nutr*., **44(15)**, 2253-2265.

Kumar, V., Jat H.S., Sharma P.C., Gathala M.K., Malik R.K. and Kamboj B.R. (2018). Can productivity and profitability be enhanced in intensively managed cereal systems while reducing the environmental footprint of production? Assessing sustainable intensification options in the breadbasket of India. *Agric. Ecosyst. Environ*., **252**, 132–147.

Kumar, V., Sharma P. and Verma A. (2023). Integrated nutrient management for sustainable crop production. *Agric. Res. J.*, **60(2)**, 112-125.

Kumar, V., Singh S. and Kumar R. (2019). Effect of Organic Manures on Soil Health and Crop Yield in Wheat. *IJCMAS*, **8(5)**, 2452-2460.

Leghari, S.J., Wahocho N.A., Laghari G.M., Laghari A.H., Bhabhan G.M., Talpur K.H., Bhutto T.A., Wahocho S.A. and Lashari A.A. (2016). Role of nitrogen for plant growth and development. *Adv. Environ. Biol.*, **10(9)**, 209-218.

Meena, H.M., Datta S., Pathak H. and Saha R. (2015). Soil health and climate change: A case study on rice-wheat cropping system. *IJBSM*, **6(4)**, 444-450.

Meena, V.S., Maurya B.R. and Verma R. (2021). Role of Bio-enhancers in Sustainable Agriculture: A review. *J. Plant Nutr*., **44(12)**, 1891-1912.

NAAS (2017). *Management of Crop Residues in the Context of Conservation Agriculture*. Policy Paper No. 82. National Academy of Agricultural Science, New Delhi, India.

Natarajan, K. (2007). *Panchagavya for plant growth and soil health*. Published by Other India Press.

Olsen, S.R. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate (No. 939). US Department of Agriculture.

Palekar, S. (2006). The principles of spiritual farming. Zero Budget Natural Farming Research, Development & Extension Movement, Amravati, Maharashtra, India.

Paramesh, V., Mohan Kumar R., Rajanna G.A., Gowda S., Nath A.J., Madival Y., Jinger D., Bhat S. and Toraskar S. (2023). Integrated nutrient management for improving crop yields, soil properties and reducing greenhouse gas emissions. *Front. Sustain. Food Syst.*, **7**, 1173258.

Patel, A.M., Sharma R.S. and Kumar P. (2022). Impact of Organic and Inorganic Fertilizers on Crop Yield and Soil Properties. *Agric. Res*., **11(3)**, 431-440.

Patel, J., Patel R., Patel K. and Patel N. (2020). Effect of organic and inorganic fertilizers on soil properties and yield of maize. *JPP*, **9(3)**, 549-553.

Patel, J., Sharma V. and Kumar R. (2023). Influence of Organic and Inorganic Fertilizers on Soil Health and Crop Productivity. *Agric. Ecosyst. Environ*., **338**, 108140.

Patel, R., Singh D. and Sharma N. (2023). Synergistic effects of organic and inorganic fertilizers on legume yields. *J. Agron. Crop Sci*., **209(1)**, 45-56.

Pathak, H., Tewar A.N., Sankhyan S., Dubey D.S., Mina U. and Singh V.K. (2011). Direct-seeded rice: potential, performance and problems – a review. *Curr. Adv. Agric. Sci*., **3**, 77–88.

Plaza-Bonilla, D., Nolot J.M., Raffaillac D. and Justes E. (2013). Cover crops mitigate nitrate leaching in cropping systems including grain legumes: Field evidence and model simulations. *Agric. Ecosyst. Environ*., **165**, 1-10.

Ramesh, B., Kaur M. and Chhabra V. (2023). Effect of Integrated Nutrient Management on Growth and Yield Parameters of Maize (*Zea mays*) (Poaceae). *Int. J. Environ. Clim.*, **13(8)**, 874-880.

Rathore, N., Bhatt R. and Pandey S. (2022). Impact of Jeevamrit and Beejamrit on soil health and crop productivity. *Indian J. Agric. Sci*., **92 (3)**, 323-330.

Samuel, A.L., Joseph O.L. and Okereke N.C. (2018). Influence of poultry manure and NPK fertilizer on soil properties and growth of maize. *J. Agric. Ecol*., **15(2)**, 1-8.

Schjonning, P., Elmholt S. and Christensen B.T. (Eds) (2002). *Managing soil quality: Challenges in modern agriculture*. CABI Publishing.

Sharma, P., Singh S. and Dhaliwal S.S. (2022). Integrated Nutrient Management for Sustainable Agriculture. *Int. J. Plant Prod.*, **16(3)**, 407-420.

Sharma, R., Singh J. and Kaur H. (2022). Enhancing biomass production through integrated nutrient management. *J. Plant Nutr*., **45(10)**, 1505-1517.

Sharma, S., Kaur H. and Gill B.S. (2020). Enhancing Crop Productivity through Integrated Nutrient Management. *J. Agron*., **19(4)**, 255-264.

Singh, J., Singh G. and Singh P. (2020). Effect of Organic and Inorganic Nutrient Sources on Growth and Yield of Wheat. *J. Agric. Sci.*, **12(2)**, 123-130.

Singh, P. and Singh R. (2021). Organic amendments and their role in sustainable agriculture. *Int. J. Sustain. Agric.*, **19(4)**, 287-298.

Sitthaphanit, S., Jamjod S., Rerkasem B. and Jearakongman S. (2010). Effects of split application of nitrogen on yield and grain quality in irrigated lowland rice. *Field Crops Res*., **118(3)**, 289-293.

Sreenivasa, M.N., Naik N.M. and Bhat S.N. (2010). Beejamruth: A source for beneficial bacteria. *J. Karn. Agric. Sci*., **17**, 72-77.

Swaminathan, M.S. (1998). Implementing the vision of a world with zero hunger. *Agric. Econ*., **18(1)**, 1-15.

Tilman, D., Balzer C., Hill J. and Befort B.L. (2011). Global food demand and the sustainable intensification of agriculture. *Proc. Natl. Acad. Sci*., **108**, 20260–20264.

Vetter, S.H., Sapkota T.B., Hillier J., Stirling C.M., Macdiarmid J.I. and Aleksandrowicz L. (2017). Greenhouse gas emissions from agricultural food production to supply Indian diets: implications for climate change mitigation. *Agric. Ecosyst. Environ*., **237**, 234–241.

Walkley, A. and Black I.A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *S. Sci*., **37(1)**, 29-38.

Wei, D., Yang C., Xu R., Zhu Y. and Fan X. (2015). Effects of replacing rice with maize on soil properties and enzyme activities. *J. Soil Sci. Plant Nutr*., **61(1)**, 33-45.

Yadav, A., Yadav D.S. and Singh R. (2020). Influence of Bio-fertilizers and Organic Manures on Soil Health and Crop Yield. *Int. J. Environ. Sci*., **46(4)**, 337-347.

Yadav, R.L., Dwivedi B.S. and Prasad K. (2000). Yield trends, and changes in soil organic-C and available NPK in a long-term rice-wheat system under integrated use of manures and fertilizers. *Field Crops Res*., **68(3)**, 219-246.

Zhu, Y., Chen H., Fan J., Wan Y., Li Y., Chen J., Fan J., Yang S., Hu L., Leung H., Mew T.W., Teng P.S., Wang Z. and Mundt C.C. (2000). Genetic diversity and disease control in rice. *Nature*, **406**, 718-722.