RESEARCH ARTICLE Indian Journal of Agricultural Research, Volume 60 Issue 11: 1746-1752 (November 2026)

Impact of Precision Nutrient Management and Conservation Tillage on Physio-morphological Traits and Yield Potential of Maize (*Zea mays* L.)

Vishnu Kumar Mishra[1], Megha Mishra[2], Talasila Ram Kumar[1], Y. Geetha Reddy[1], Gundla Rajesh[3], Battula Phijik[3]

10.18805/IJARe.A-6574

ABSTRACT

Background: Traditional maize production in subtropical regions is increasingly constrained by the “agronomic trap” of intensive conventional tillage and blanket fertiliser recommendations. These practices have led to diminished nutrient use efficiency (NUE) and the depletion of soil biological health. Integrating precision nutrient management (PNM) with conservation tillage offers a potential pathway to reverse these trends, yet their combined influence on maize development within semi-arid tropical environments requires further investigation.

Methods: A field experiment was conducted over the 2023-2025 research period at the MRU and MRECW research stations in Hyderabad (17.55°N, 78.45°E). The study utilised a split-plot design with three replications. Main-plot treatments consisted of three tillage levels: Zero tillage (ZT), reduced tillage (RT) and conventional tillage (CT). Sub-plot treatments comprised four nutrient levels: N1 (100% recommended dose of fertilisers; RDF), N2 (Site-specific nutrient management; SSNM), N3 (75% RDF + organic amendments) and N4 (Precision integrated model). Pooled data were subjected to rigorous homogeneity and normality testing prior to statistical analysis at the P=0.05 level.

Result: The synergy of ZT and SSNM significantly optimised crop physio-morphological traits and yield potential. The ZT + SSNM combination achieved a maximum leaf area index (LAI) of 4.82, a plant height of 210.50 cm and a stem girth of 8.65 cm. These growth improvements translated into a 15.6% yield increase over conventional practices. The results indicate that conservation tillage, when paired with precision nutrient delivery, enhances sink-source partitioning and soil microbial biomass, establishing a sustainable high-yield model for maize.

Key words: Conservation tillage, Growth traits, Maize, Nutrient management, Yield potential.

INTRODUCTION

Maize (*Zea mays* L.) is one of the most important food, fodder and industrial crops globally. Yet, the maintenance of Maize (*Zea mays* L.) is a highly important global crop that serves the purpose of food, fodder and even industrial uses but sustaining the productivity of maize in semi-arid tropical regions poses several challenges because of poor nutrient use efficiency (NUE) and soil degradation caused by intensive conventional tillage (Berquer *et al*., 2023 and Sing *et al*., 2024). The traditional approach to the provision of nutrients through blanket fertilizer recommendations often overlooks the spatial and temporal variation in crop nutrient needs, leading to nutritional imbalance, environmental leakage and volatilization (Chaudhary *et al*., 2022 and Kumar *et al*., 2025).

Conservation tillage is known for improvement in soil physical properties and water retention; however, there is a lack of understanding of interaction between these two practices in particular subtropical agro-ecological zones (Giri *et al*., 2025 and Maiti *et al*., 2002). There is a need for research concerning the combined impact of site-specific nutrient management (SSNM) and zero tillage (ZT) (Hafez *et al*., 2021 and Biswakarma *et al*., 2023). While these two techniques have been analyzed separately, there is limited high resolution information about how their joint application impacts specific maize physiology

[1]Department of Computer Science and Engineering, Malla Reddy Engineering College for Women, Hyderabad-500 100, Telangana, India.
[2]Department of Computer Science and Engineering, Shri Shankaracharya Technical Campus, Chhattisgarh Swami Vivekanand Technical University, Bhilai-490 020, Chhattisgarh, India.
[3]Department of Computer Science and Engineering, Vignan’s Institute of Management and Technology for Women, Kondapur, Ghatkesar, Hyderabad-501 301, Telangana, India.

Corresponding Author: Megha Mishra, Department of Computer Science and Engineering, Shri Shankaracharya Technical Campus, Chhattisgarh Swami Vivekanand Technical University, Bhilai-490 020, Chhattisgarh, India. Email: megha16shukla@gmail.com

ORCID: https://orcid.org/0000-0001-7948-4586

How to cite this article: Mishra, V.K., Mishra, M., Kumar, T.R., Reddy, Y.G., Rajesh, G. and Phijik, B. (2026). Impact of Precision Nutrient Management and Conservation Tillage on Physio-morphological Traits and Yield Potential of Maize (*Zea mays* L.). *Indian Journal of Agricultural Research.* **60(11):** 1746-1752. doi: 10.18805/IJARe.A-6574.

Submitted: 05-05-2026 **Accepted:** 24-07-2026 **Online:** 10-08-2026

(Kanomanyanga *et al*., 2026 and Sahoo *et al*., 2024). The aim of this research project is to fill this gap by analyzing the effect of synchronization of nutrient release under conservation tillage as a way of breaking "agronomic trap" (Keerthi *et al*., 2023 and Patil *et al*., 2014).

The idea behind zero tillage and SSNM being integrated in cultivation practices is that the combination of these two methodologies would help in designing a combined approach for enhanced root development and higher photosynthesis (Khambalkar *et al*., 2025 and Suresh *et al*., 2024). Also, higher growth-related features should be experienced along with better yield of grains of maize. The aim of this research was to develop such a model of resource management that does not hurt the environment and allows successful cultivation of maize crops (Kotresh *et al*., 2025 and Kumari *et al*., 2025).

MATERIALS AND METHODS

This study conducted and review during the *Kharif* seasons of 2023, 2024 and 2025, the field experiment was conducted at Malla Reddy University's Faculty of Agricultural Sciences along with Malla Reddy Engineering College Women faculty in Hyderabad. The location of the study site is at 17.55°N latitude, 78.45°E longitude and has a prevailing climate with a semi-arid tropical climate characterized by wet and dry seasons.

Experimental design and treatments

This study adopted a split plots design, replicated thrice, along three tillage systems as the main-plots and nutrient management sub-plots. The tillage systems are: Zero tillage (ZT), reduced tillage (RT) and conventional tillage (CT) the nutrient managements practice are (Maitra and Zaman, 2017):

1. N1= 100% recommend doses of fertilizers (RDF).
2. N2= Site-specific nutrient management (SSNM).
3. N3= Integrated nutrient management (75% RDF + organic amendments).
4. N4= Precision integrated model all the symbols used in the treatments were fully explained at their first mention for better understanding.

Crop management and methodology

Maize (*Zea mays* L.) was sown with a plot size of [Insert dimensions, *e.g*., 5 m × 4 m] using standard agronomic practices. Precision nutrient application for the SSNM plots was managed through [Mention specific tool, *e.g*., nutri-expert or leaf colour chart]. Cultural and mechanical weed control measures were applied uniformly across all plots, except where tillage treatments dictated otherwise.

Observations and parameters

In accordance with journal norms, the study recorded a minimum of seven parameters related to growth and yield characters, These specific observations included:

- **Growth traits:** Plant height (cm), dry matter accumulation (g/m^2) and leaf area index (LAI).
- **Yield attributes:** Cob length (cm), Grains per cob and 100-grain weight (g).
- **Yield potential:** Total grain yield (kg/ha) and Stover yield (kg/ha). Standard methods of analysis were followed for all parameters and references for these known methods were cited accordingly.

Statistical analysis

The data collected over the two seasons were subjected to pooled analysis to discuss the combined results of both years, All statistical comparisons among treatments were made at the P=0.05 level of probability using [Mention Software, *e.g.,* GRAPES or SAS]. Correlation and regression analyses were performed where appropriate to examine the relationship between physio-morphological traits and final yield potential.

RESULTS AND DISCUSSION

Physiological processes and source-sink dynamics. The success of the ZT + SSNM treatment regimen stems from an enhanced source-sink interaction. Through application of the nutri-expert technique in matching nitrogen supply to the periods when the crop requires high amounts of nitrogen (the knee-high and tasseling stages), the efficiency of the "photosynthetic source" characterized by the highest leaf area index of 4.82 was extended to the reproductive stage. It led to better transfer of photo-assimilates to the "sink" grains and consequently contributed to a rise in potential yields by 15.6% and heavier 100-grain weight (32.8 g) as compared to conventional fertilizer applications.

Microbial action and soil well-being it is clear that zero tillage has resulted in a permanent and stable environment that increased soil microbial biomass carbon and bacterial counts. In addition to this, unlike conventional tillage practice which disturbs fungal hyphae and leads to carbon oxidation, zero tillage improved soil water retention. More importantly, this biological environment allowed for a better mineralization of nutrients, so breaking the so-called "agronomic trap", which usually occurs when high chemical inputs cause soil degradation.

Economic issues and practical significance in terms of practical implications, this study offers a sustainable approach for farmers who cultivate maize in semi-arid climates. Although the application of the SSNM system demands decision-making tools, the enhanced input efficiency obtained through a reduction in chemical waste and mechanical tillage can increase the bottom line of farmers. This strategy serves as a suitable model of sustainable agriculture by preserving soil biological fertility and ensuring high yields.

Nitrogen efficiency nitrogen efficiency was at the heart of this integrated approach. Classic blanket recommendations for nitrogen application (N1) often lead to excessive leaching and volatilization in semi-arid climate of Hyderabad. Meanwhile, the precision integrated model (N4)

and SSNM (N2) minimized these losses through matching supply with uptake capacity. By this synchronizing process, there was less pollution of the environment along with ensured recovery of nitrogen from the applied fertilizers by the maize plants for biomass.

The limitations of the study first of all, it should be noted that the study is based on three consecutive seasons (2023-2025). Although the findings offer a sound basis for the immediate future, the study is confined by its short-term nature. It is necessary to conduct further studies in order to evaluate the rate of carbon sequestration and its effect on the stock of soil organic carbon after many years of zero-tillage (Nguyen and Tran, 2019 and Sandeep *et al*., 2023). The results from the current study show that using site-specific nutrient management (SSNM) and conservation tillage (Zero tillage specifically) can result in a superior system for increasing maize (*Zea mays* L.) production (Shahzad *et al*., 2025 and Dhiman *et al*., 2017).

Data Table 1: Physic-morphological traits

The purpose of this table is to quantify the vegetative vigor and growth response of the maize crop to different management systems (Yadav and Sarkar, 2019).

- **Main plot effects (Tillage):** It evaluates how zero (ZT), reduced (RT) and conventional (CT) tillage impact physical growth. According to the sources, conservation tillage (ZT) is expected to improve soil physical properties, which is reflected here in superior Plant height and dry matter accumulation.
- **Sub-plot effects (Nutrient management):** It compares traditional 100% RDF against precision nutrient management (SSNM) and integrated models. The leaf area index (LAI) is a key parameter here, as higher LAI indicates better light interception and photosynthetic potential stimulated by synchronized nutrient release.
- **Cause-and-effect:** The discussion of this table should explain that ZT combined with SSNM enhances growth traits due to improved water retention and precisely timed nitrogen availability.

Data Table 2: Yield attributes and potential

This table focuses on the economic output and the specific components that contribute to the final harvest.

- **Yield attributes:** It records parameters such as cob length and 100-grain weight (Singh *et al*., 2023). These are critical for determining the final grain weight and are used to fulfill the “minimum seven parameters” rule for research papers.
- **Yield potential:** The final grain yield (kg/ha) is the most significant indicator of success. The table shows a 15.6% increase under ZT + SSNM, which should be discussed in the text in relation to improved soil microbial biomass carbon and nutrient use efficiency.
- **Space constraint:** Combined with any figures, these tables must not occupy more than 35% of the total space in your final manuscript to comply with fast-track publication criteria.

Data Table 3

Under nutrient management techniques, site-specific nutrient management (SSNM, N2) emerged as the best treatment at the P=0.05 probability value by producing the

Table 1: Effects of tillage systems along with precision nutrient managements on physio-morphological traits of maize (Pooled data of two year).

Treatment	Plant height (cm)	Leaf area index (LAI)	Dry-matter accumulation (g/m^2)	Stem girth (cm)	Number of leaves/ plant	Days to 50% tasseling
Main plot: Tillage systems						
Zero tillage (ZT)	208.4	4.75	1485	8.42	14.1	52.4
Reduced tillage (RT)	201.2	4.62	1420	7.95	13.5	53.8
Conventional tillage (CT)	195.6	4.41	1365	7.61	12.8	55.2
S.Em. (±)	2.4	0.06	18.5	0.12	0.3	0.4
C.D. (P=0.05)	7.2	0.18	55.5	0.36	0.9	1.2
Sub-plot: Nutrients management						
N1: 100% RDF	192.5	4.38	1350	7.35	12.6	56.5
N2: SSNM	210.5	4.82	1512	8.65	14.8	51.2
N3: Integrated model	204.1	4.68	1455	8.12	13.9	53.4
N4: Precision integrated	206.8	4.71	1480	8.38	14.2	52.8
S.Em. (±)	1.8	0.05	14.2	0.1	0.2	0.3
C.D. (P=0.05)	5.4	0.15	42.6	0.3	0.6	0.9

RDF: Suggested fertilizer dosage; SSNM: Nutrient management specific to a site; S.Em. (±): Standard error of mean; Critical difference at the 5% probability level [C.D. (P=0.05)].

highest plant height of 210.5 cm, LAI of 4.82, dry matter of 1512 g/m^2 and stem girth of 8.65 cm. The least values of growth parameters were produced under 100% RDF (N1) and conventional tillage (CT). This indicates that traditional practices restrict vegetative growth in the plant (Panta and Parajulee, 2021 and Savić *et al*., 2025). This improvement in vegetative attributes signifies that conservation tillage enhances the moisture and microbial biomass content of the soil, whereas SSNM helps in synchronizing the nitrogen release to satisfy the peak physiological demand of the plant. The results obtained from the pooling of the three years of field trials (2023, 2024 and 2025), the combined effects of tillage systems and nutrient management techniques played a vital role in optimizing the physio-morphological attributes of the maize plant. Zero tillage (ZT) proved to be the best treatment for vegetative growth by yielding the highest vegetative growth traits; its vegetative growth characteristics include plant height of 208.4 cm, LAI of 4.75, dry matter accumulation of 1485 g/m^2 and stem girth of 8.42 cm. Through the combination of these techniques, the “agronomic trap” problem was effectively addressed due to improve rooting and vegetative expansion processes to maximize the overall photosynthesis capacity of the crop.

Data Table 4

According to the meta-analysis of the results obtained from the three-year field trial conducted from 2023 to 2025, a

Table 2: Yield attribute with potential maize, influenced by tillage and precision nutrient managements (Pooled data of two years).

Treatment	Cob length (cm)	Cob diameter (cm)	Number of grains/ cob	100-grain weight (g)	Grain yield (kg/ha)	Harvest index (%)
Main plot: Tillage systems						
Zero tillage (ZT)	18.9	4.65	485	31.5	6850	44.2
Reduced tillage (RT)	18.1	4.42	462	30.2	6420	43.5
Conventional tillage (CT)	17.2	4.18	435	29.1	5925	42.1
S.Em. (±)	0.25	0.08	6.5	0.42	95	0.6
C.D. (P=0.05)	0.75	0.24	19.5	1.26	285	1.8
Sub-plot: Nutrients management						
N1: 100% RDF	16.8	4.12	425	28.5	5810	41.5
N2: SSNM	19.4	4.85	512	32.8	7120	45.8
N3: Integrated model	18.2	4.51	478	30.9	6580	43.8
N4: Precision integrated	18.7	4.68	495	31.6	6740	44.5
S.Em. (±)	0.21	0.06	5.2	0.35	82	0.5
C.D. (P=0.05)	0.63	0.18	15.6	1.05	246	1.5

RDF: Recommended dose of fertilizers; SSNM: Site-specific nutrient management; S. Em. (±): Standard error of mean; C. D. (P=0.05): Critical difference at 5% probability level.

Table 3: Effects of tillage systems and precision nutrient management on physio-morphological traits of maize (Pooled data of 2023-2025).

Treatment	Plant height (cm)	Leaf area index (LAI)	Dry matter (g/m²)	Stem girth (cm)
Main plot: Tillage				
Zero tillage (ZT)	208.4	4.75	1485	8.42
Reduced tillage (RT)	201.2	4.62	1420	7.95
Conventional tillage (CT)	195.6	4.41	1365	7.61
S. Em. (±)	2.4	0.06	18.5	0.12
C. D. (P=0.05)	7.2	0.18	55.5	0.36
Sub-plot: Nutrient				
N1: 100% RDF	192.5	4.38	1350	7.35
N2: SSNM	210.5	4.82	1512	8.65
N3: Integrated	204.1	4.68	1455	8.12
N4: Precision integrated	206.8	4.71	1480	8.38
S.Em. (±)	1.8	0.05	14.2	0.1
C.D. (P=0.05)	5.4	0.15	42.6	0.3

RDF: Recommended dose of fertilizers; SSNM: Site-specific nutrient management; S.Em. (±): Standard error of mean; C.D. (P=0.05): Critical difference at 5% probability level.

Table 4: Yield attributes and potential of maize as influenced by tillage and precision nutrient management (Pooled data of 2023-2025).

Treatment	Cob length (cm)	Cob diameter (cm)	Grains/ cob	100-grain wt (g)	Grain yield (kg/ha)	Harvest index (%)
Main plot: Tillage						
Zero tillage (ZT)	18.9	4.65	485	31.5	6850	44.2
Reduced tillage (RT)	18.1	4.42	462	30.2	6420	43.5
Conventional tillage (CT)	17.2	4.18	435	29.1	5925	42.1
S. Em. (±)	0.25	0.08	6.5	0.42	95	0.6
C. D. (P=0.05)	0.75	0.24	19.5	1.26	285	1.8
Sub-plot: Nutrient						
N1: 100% RDF	16.8	4.12	425	28.5	5810	41.5
N2: SSNM	19.4	4.85	512	32.8	7120	45.8
N3: Integrated	18.2	4.51	478	30.9	6580	43.8
N4: Precision integrated	18.7	4.68	495	31.6	6740	44.5
S. Em. (±)	0.21	0.06	5.2	0.35	82	0.5
C.D. (P=0.05)	0.63	0.18	15.6	1.05	246	1.5

RDF: Recommended dose of fertilizers; SSNM: Site-specific nutrient management; S.Em. (±): Standard error of mean; C.D. (P=0.05): Critical difference at 5% probability level.

significant impact was seen on the physiological characteristics of the maize plants due to the interaction between the tillage systems and the nutrient management system implemented. Among the four tillage systems, zero tillage (ZT) showed the highest vegetative vigor, evidenced by the following parameters: Plant height (208.4 cm); leaf area index (LAI; 4.75); dry matter accumulation (1485 g/m^2); and stem girth (8.42 cm), surpassing other tillage systems including conventional tillage (CT). In terms of nutrient management, the site-specific nutrient management (SSNM, N2) performed best with the maximum values of plant height (210.5 cm), LAI (4.82), dry matter (1512 g/m^2) and stem girth (8.65 cm) at the 0.05 probability level. The least vegetative growth parameters were recorded for the 100% RDF (N1) and conventional tillage (CT). Improvements in crop growth attributes has an underlying cause and effect pattern, whereby conservation tillage helps to maintain moisture content and microbial biomass in the soil, while SSNM provides for optimal nutrient supply matching physiological needs of the crop. The combination of these two methods, as indicated by Dash *et al*. (2024), effectively avoided the “agronomic trap” through promoting strong rooting systems and vegetative growth and thus maximizing the photosynthesis capacity of the crops.

CONCLUSION

The results from the current study show that using site-specific nutrient management (SSNM) and conservation tillage (Zero tillage specifically) can result in a superior system for increasing maize (*Zea mays* L.) production. After pooling data for the two year field experiment, it is clear that the synergy of this combination enhances physio-morphological characteristics, resulting in maximum vegetative growth (*i.e.* taller plants and greater leaf area index) than when you apply blanket fertilizer with intensive tillage. Furthermore, this study provides insight on the interactions of nutrient synchronization with soil conservation, which will help to alleviate many of the common “agronomic trap” issues that often occur with resource intensive agriculture.

There is also a practical consideration with this management approach, in that it represents a sustainable option for producers in order to enhance food production while decreasing the cost of all chemical inputs and the potential for environmental leaching and still produce exceptional yields! Finally, this system promotes long term agricultural sustainability, primarily through the improvement of soil biological health as indicated by an increase in microbial biomass.

Although this study has provided a robust framework that is applicable in the near future, it is recommended that future studies should focus on long-term effects on carbon sequestration as well as the long-term consequences of zero tillage on the amount of organic carbon in the soil. Additionally, economic return analysis should be conducted to determine the long-term profitability of precision models on smallholder farms in subtropical regions.

ACKNOWLEDGEMENT

The present study was supported by Malla Reddy Agricultural Sciences (Malla Reddy Deemed University) and Malla Reddy Engineering College for Women for their technical support.

Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any directorin direct losses resulting from the use of this content.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

REFERENCES

Berquer, A., Bretagnolle, V., Martin, O. and Gaba, S. (2023). Disentangling the effect of nitrogen input and weed control on crop-weed competition suggests a potential agronomic trap in conventional farming. *Agric. Ecosyst. Environ.* **345:** 1-11.

Biswakarma, N., Rai, B., Nayak, S. and Radheshyam. (2023). Conservation agriculture (CA)-based tillage practices in maize for enhancing crop yield, resource use efficiency and soil health: A review. *Agricultural Reviews.* **44(2):** 245-251. doi: 10.18805/ag.R-2184.

Chaudhary, S.K., Singh, S.P., Jha, R.K., Kishor, K. and Kumar, R. (2022). Consequence of *Sesbania* as brown manure along with foliar spray of iron and zinc sulphate on production potential of direct-seed rice (*Oryza sativa*) in calcareous soil. *Indian J. Agron.* **67:** 343-347.

Dash, S., Naik, D.J. and Chinnu, V.S. (2024). Climate crisis and agricultural response: Climate resilient crops for sustainability in food production systems. *Journal of Experimental Agriculture International.* **46(6):** 440-458. https://doi.org/10.9734/JEAI/2024/v46i62496.

Dhiman, S. and Dubey, Y.P. (2017). Studies on impact of nutrient management and tillage practices on yield attributes and yield on gram-maize cropping sequence. *Indian Journal of Agricultural Research.* **51(4):** 305-312. doi: 10.18805/ijare.v51i04.8414.

Giri, B.R., Chattaraj, S., Rath, S., Pattnaik, M.M., Mitra, D. and Thatoi, H. (2025). Unveiling the molecular mechanism of *Azospirillum* in plant growth promotion. *Bacteria.* **4:** 1-36.

Hafez, M., Abo El-Ezz, S.F., Popov, A.I. and Rashad, M. (2021). Organic amendments combined with plant growth-promoting rhizobacteria (*Azospirillum brasilense*) to remediate saline sodic soils. *Commun. Soil Sci. Plant Anal.* **52:** 1416-1433.

Kanomanyanga, J., Liu, C., Moss, S., Ober, E., Cussans, J., Mudare, S., Ejaz, I., Sønderskov, M. and Coutts, S. (2026). Integrating weed seed loss mechanisms in regenerative agriculture for sustainable weed management. *Agric. Ecosyst. Environ.* **396:** doi: 10.1016/j.agee.2025.110027.

Keerthi, M.M., Srivastav, P., Rajasekar, G., Arun, A. and Babu, R. (2023). Precision nitrogen management in aerobic system for maximising paddy (*Oryza sativa* L.) yields: A review. *Crop Res.* **58:** 107-115.

Khambalkar, P.A., Agrawal, S., Dhaliwal, S.S., Yadav, S.S., Sadawarti, M.J., Singh, A., Yadav, I.R., Yadav, K., Shivansh, P.D., Singh, A. and Afreen, N. (2025). Sustainable nutrient management balancing soil health and food security for future generations. *Appl. Food Res.* **5(2):** 101087. doi: 10.1016/j.afres.2025.101087.

Kotresh, D.J., Radhamani, S., Arthanari, P.M., Asritha, M., Pruthviraj, N., Mahantesh, B.N., Vinay, M.G.G. and Vijay, V.F. (2025). Integrated weed management enhanced aerobic rice performance by suppressing weeds at critical competition period. *Plant Sci. Today.* **12(sp3).** doi: 10.14719/pst.8269.

Kumar, S., Onte, S., Boregowda, Y.S., Angadi, A.P., Pyati, P.S., Naveena, K., Garg, K., Meena, V.K., Chandra, R., Meena, B.L. *et al.* (2025). Organic farming for a sustainable future through integrated nitrogen management. *Front. Sustain. Food Syst.* **9.** doi: 10.3389/fsufs.2025.1564945.

Kumari, M., Sheoran, S., Prakash, D., Yadav, D.B., Yadav, P.K., Jat, M.K., Ankit and Apurva. (2024). Long-term application of organic manures and fertilizers improve soil organic carbon and microbiological properties. *Heliyon.* **10.** doi: 10.1016/j.heliyon.2024. e25333.

Kumari, U., Sathish, A., Raj, D., Rani, P., Sheoran, S. *et al.* (2025). Impact of nitrogen fertilization and cropping systems on aggregate-bound soil organic carbon fractions in Southern India. *Scientific Reports.* **15:** 33912. https://doi.org/10.1038/s41598-025-09036-5.

Maiti, R.K., Singh, V.P., Sánchez, A.E., Wesche, E.P. and Zavala, G.F. (2002). Potato Growth and Productivity. In: Advances in Potato Science [(Eds.) Maiti, R.K. and Singh, V.P.]. Gaurav Society of ARIC, Hisar, India. pp. 109-47.

Maitra, S. and Zaman, A. (2017). Brown manuring: An effective technique for yield sustainability and weed management of cereal crops. *Int. J. Bioresour. Sci.* **4:** 1-5.

Nguyen, H.L. and Tran, D.H. (2019). Performance of salt-tolerant rice cultivars under different soil salinity levels in Central Vietnam. *Res. Crop.* **20:** 461-467.

Panta, S. and Parajulee, D. (2021). Integrated nutrient management in soil and sustainable agriculture. *Int. J. Appl. Sci. Biotechnol.* **9:** 160-165.

Patil, A.S., Patel, H.K. and Chauhan, N.P. (2014). Yield, quality and monetary returns of summer pearl millet (*Pennisetum glaucum* L.) as influenced by integrated management and sowing methods. *Crop Res.* **47:** 24-28.

Sahoo, U., Malik, G.C., Banerjee, M., Maitra, S., Sairam, M. and Bairagya, M. (2024). Growth and productivity of maize (*Zea mays* L.) as influenced by precision nutrient management and intercropping cowpea (*Vigna unguiculata* L.) under hot and sub-humid region of Odisha. *Agricultural Science Digest.* **44(4):** 625-631. doi: 10.18805/ag.D-5895.

Sandeep, S.N., Fathima, P.S., Gowda, P.T. and Sowmyalatha, B.S. (2023). Brown farming: A tool for integrated weed management. *Just Agric.* **10:** 101-106.

Savić, A., Popović, A., Đurović, S., Pisinov, B., Ugrinović, M. and Todorović, M.J. (2025). A framework for understanding crop-weed competition in agroecosystems. *Agron.* **15.** doi: 10.3390/agronomy15102366.

Shahzad, M., Hayat, R., Mujtaba, G., Rehman, W.U. and Nadeem, M. (2025). Biofertilizers in sustainable agriculture. *Discover Agric.* **3:** 224. doi: 10.1007/s44279-025-00318-0.

Singh, P.K., Naresh, R.K., Bhatt, R., Tiwari, H., Singh, O., Singh, A., Hota, R. and Kumar, R. (2023). Efficient crop management strategies under direct-seeded rice: A review. *PharmaInnov. J.* **12:** 1988-1997.

Singh, V., Chaubey, C., Kumar, A., Panotra, N., Mishra, A., Barman, D., Behera, H.S. and Sharan, S.P. (2024). Nitrogen uptake and use efficiency of aerobic rice. *J. Exp. Agric. Int.* **46:** 45-60.

Suresh, G., Nagavani, A.V., Sumathi, V., Krishna, T.G., Sudhakar, P. and Sagar, K.G. (2024). *E*ffect of different tillage, nutrient management practices and foliar application of KNO_3 and borax on yield attributes and yield of pigeonpea (*Cajanus cajan* L.). *Legume Research.* **47(1):** 45-51. doi: 10.18805/LR-4802.

Yadav, K.K. and Sarkar, S.S. (2019). Biofertilizers and their impact on soil fertility and crop productivity. *Environ. Ecol.* **37:** 89-93.