Experiment Title: Integrated Tillage and Bio-Organic Phosphorus Management for Improving P Availability, P-Use Efficiency and Productivity of Calcareous Rice-Based Cropping Systems in North Bihar

(under Project: Soil health driven cropping system design and resource efficient planting strategies for ecosystems of eastern India)

Item	Details
1. Title of the project	Experiment title: Integrated Tillage and Bio-Organic Phosphorus Management for Improving P Availability, P-Use Efficiency and Productivity of Calcareous Rice-Based Cropping Systems in North Bihar (under Project: Soil health driven cropping system design and resource efficient planting strategies for ecosystems of eastern India)
2. Funding agency	Institute funded (ICAR–MGIFRI)
3. Total outlay	
4. Duration	36 months (July 2026–July 2029)
5. Single/Multi-institutional	Single institutional
6. Lead Centre if multi-institutional	Not applicable
7. Cooperating Centre(s)	Not applicable
8. Principal Investigator	Dr. Vijay Singh Meena, Senior Scientist (Soil Science), ICAR–MGIFRI;
9. Co-Investigators	Dr. Subham Mukherjee, Scientist (Soil Science), ICAR–MGIFRI (Experiment Lead) Dr. Koushik Banerjee, Scientist (Agricultural Meteorology), ICAR–MGIFRI

10. Rationale

Phosphorus (P) management is a major constraint to sustainable crop production in the calcareous alluvial soils of North Bihar. These soils commonly contain appreciable reserves of total phosphorus but support comparatively low concentrations of readily plant-available P. This creates an apparent contradiction in which soils may contain substantial amounts of phosphorus and yet crops continue to respond to fresh P fertilization. The problem is associated principally with the alkaline reaction and presence of free calcium carbonate, which favour rapid sorption and precipitation of soluble fertilizer P into comparatively less soluble calcium-associated forms. Consequently, only a relatively small proportion of freshly applied fertilizer P is recovered by crops during the season of application, while the remaining P progressively contributes to a residual or legacy soil-P pool.

Phosphorus is particularly difficult to manage because it is relatively immobile in soil and reaches plant roots mainly through short-distance diffusion. Crop uptake therefore depends not only on the total amount of phosphorus present in the soil but also on its chemical availability, spatial distribution, soil moisture, root proliferation and biological mobilization. These limitations become particularly important in intensive rice-based cropping systems, where repeated fertilizer application, wetting-drying cycles, low soil organic carbon and conventional tillage can progressively reduce the efficiency with which applied P is utilized.

A practical strategy is therefore required that improves access to both freshly applied and accumulated soil P rather than simply increasing fertilizer rates. Band placement can reduce fertilizer–soil contact and concentrate phosphorus close to the developing root system, thereby improving early

P availability. Organic amendments such as FYM can contribute directly to the P pool while supplying organic carbon, improving soil physical condition and influencing P sorption and precipitation reactions. Phosphate-solubilizing bacteria (PSB) may further enhance P mobilization through organic-acid production, chelation and phosphatase activity. These mechanisms provide the scientific basis for evaluating reduced mineral-P application in combination with FYM and PSB.

The effectiveness of these P-management strategies may also depend strongly on the cropping and tillage system. Conventional puddling and intensive tillage alter soil structure, porosity and root-zone conditions, whereas reduced/zero tillage with residue retention can improve aggregation, soil moisture conservation and biological activity but can also produce marked vertical stratification of phosphorus near the soil surface. Similarly, rice–wheat–mungbean and rice–maize–mungbean systems differ in crop rooting characteristics, nutrient demand, biomass production and potential P removal. Therefore, P management should be evaluated at the whole cropping-system level rather than for an individual crop alone.

The proposed long-term field experiment consequently integrates cropping system, crop establishment/tillage and phosphorus-management strategies to determine whether mineral-P inputs can be reduced without compromising productivity. Particular emphasis will be placed on crop response, P uptake, soil-solution P, P fractions, biological P cycling, soil physical quality, P balance, system productivity and profitability. The study is expected to provide a mechanistic as well as agronomically practical basis for improving P-use efficiency in the calcareous rice-based production systems of North Bihar.

11. Research Gaps

1. Soil P dynamics under calcareous conditions are inadequately characterized. The transformation of applied and residual P among labile, organic, Fe/Al-associated, Ca-associated and residual P pools has not been adequately quantified under long-term contrasting tillage and integrated P-management systems.
2. The potential for reducing mineral-P fertilizer through improved placement remains uncertain. Although band placement should reduce soil–fertilizer contact and improve root access to P, its effectiveness relative to reduced P rates under the strongly calcareous soils of North Bihar requires field validation.
3. The ability of FYM to compensate for reduced mineral-P input is insufficiently quantified. Organic inputs may reduce P fixation, provide mineralizable P and improve biological activity, but their contribution needs to be evaluated within complete rice-based cropping sequences.
4. Field performance of PSB under alkaline-calcareous conditions remains inconsistent. PSB can mobilize sparingly soluble P, but their activity is strongly influenced by soil reaction and availability of organic carbon. The interaction of FYM and PSB therefore needs direct evaluation under field conditions.
5. Tillage-induced vertical P stratification has received inadequate attention. Reduced or zero tillage with residue retention can concentrate P in surface soil layers. Whether such stratification improves or restricts crop access to P in calcareous soil remains unresolved.
6. Cropping-system differences in P demand and residual-P utilization are poorly quantified. Rice–maize–mungbean may differ substantially from rice–wheat–mungbean in P uptake, biomass production and exploitation of residual P.
7. Whole-system P budgeting is rarely undertaken. Most studies emphasize individual crops, whereas fertilizer P, FYM-P, crop uptake, residue recycling and residual P need to be accounted for across the complete annual crop sequence.

8. Integrated soil–plant–canopy responses are poorly understood. Few long-term studies simultaneously relate soil P availability and soil physical properties with root growth, canopy development, crop physiological response, yield and P-use efficiency.
9. There is presently no adequately validated farmer-oriented package for reducing mineral-P use in calcareous rice-based systems of North Bihar.

12. Objectives

1. To evaluate the effects of cropping system, tillage/crop establishment and integrated phosphorus management on phosphorus availability, crop growth, productivity and phosphorus-use efficiency in calcareous soils.
2. To compare rice–wheat–mungbean and rice–maize–mungbean cropping systems for productivity, nutrient uptake, residual phosphorus utilization and system-level nutrient-use efficiency.
3. To assess the effect of conventional tillage and direct-seeded/reduced/zero tillage with residue retention on soil physical condition, P stratification, root-zone P availability and crop performance.
4. To quantify changes in soil phosphorus dynamics, including available P, soil-solution P, phosphorus fractions, microbial biomass P and phosphatase activity under integrated P-management practices.
5. To identify a productive, resource-efficient and economically viable P-management strategy capable of reducing mineral-P fertilizer requirement without compromising system productivity.

13. Activities

- Selection and characterization of representative calcareous experimental soil.
- Permanent layout and randomization of the long-term split–split plot experiment.
- Establishment of rice–wheat–mungbean and rice–maize–mungbean cropping systems.
- Standardization and maintenance of conventional and reduced/zero tillage systems with residue management.
- Application of mineral-P, FYM and PSB treatments.
- Seasonal monitoring of soil physical, chemical and biological properties.
- Monitoring crop growth, phenology, canopy characteristics and root development.
- Crop-wise yield and nutrient uptake assessment.
- Soil-solution P monitoring and detailed P-fractionation campaigns.
- Calculation of P-use-efficiency indices and annual/cumulative P balance.
- Assessment of system productivity, water productivity and economic performance.
- Identification of the most efficient and economically viable P-management package.

14. Details of Experiment

(a) Experimental design and treatment details

The experiment will be conducted as a split–split plot design with three replications.

Main plot factor: Cropping System – 2 levels

Code	Cropping system
C1	Rice–Wheat–Mungbean
C2	Rice–Maize–Mungbean

Sub-plot factor: Tillage/Crop Establishment – 2 levels

Code	Treatment
T1	Conventional/puddled rice followed by conventional tillage
T2	Direct-seeded/reduced-till rice followed by zero/reduced tillage with residue retention

Sub-sub plot factor: Phosphorus Management – 5 levels

Code	Treatment
P0	No phosphorus
P1	100% RDF-P through band placement
P2	50% RDF-P through band placement
P3	50% RDF-P through band placement + FYM @ 5 t ha^{-1}
P4	50% RDF-P through band placement + FYM@ 5 t ha^{-1} + PSB

Total treatment combinations = 2 × 2 × 5 = 20; with 3 replications = 60 experimental units.

(b) Fertilizer doses

- Nitrogen and potassium: Recommended dose of fertilizers (RDF) uniformly according to individual crop recommendations.
- Phosphorus: According to P0–P4 treatment structure.
- Method of P application: Band/row placement in P-amended treatments.
- FYM: Applied in P3 and P4.
- PSB: Applied in P4.

(c) Varieties

- Recommended, locally adapted and preferably ICAR/SAU-developed varieties of rice, wheat, maize and mungbean will be used.

(d) Replications: 3

(e) Observations to be recorded

1. Canopy, physiological and crop-growth parameters

NDVI, LAI, PAR interception, canopy and air temperature, SPAD/chlorophyll index, plant population, plant height, tillers/branches, dry-matter accumulation, crop growth rate, phenology, root traits, and mungbean nodulation.

2. Yield and yield attributes

Crop-specific yield attributes, grain/seed yield, straw/stover/haulm yield, test weight, and harvest index of rice, wheat, maize and mungbean.

3. Plant nutrient parameters

N, P and K concentration and uptake in grain/seed and residues, grain/seed and residue P uptake, P harvest index, and plant-tissue P.

4. Soil physical properties

Texture, bulk and particle density, porosity, soil moisture, penetration resistance, aggregate stability, water-stable aggregates, mean weight diameter, residue cover and surface residue biomass.

5. Soil chemical and phosphorus parameters

pH, EC, organic carbon, available N, P and K, total P, free $CaCO_3$, exchangeable Ca and Mg, soil-solution P, water-extractable P, and P fractions comprising labile inorganic and organic P, Fe/Al-associated P, Ca-associated P and residual P.

6. Soil biological parameters

Microbial biomass C and P, phosphatase activity, dehydrogenase activity, soil respiration and culturable PSB population.

7. Input and management parameters

FYM quality and application rate, PSB quality/viability, fertilizer inputs, crop-residue quantity and nutrient content, irrigation, rainfall, temperature, labour and machinery operations.

8. Phosphorus-use-efficiency indices

Agronomic P-use efficiency, apparent P recovery, partial factor productivity, physiological P-use efficiency, mineral-P saving, and annual/cumulative P balance.

9. System and economic parameters

Rice-equivalent yield, system productivity, total biomass, system P uptake/removal, production efficiency, water productivity, cost of cultivation, gross and net returns, B:C ratio, marginal B:C ratio and system economic efficiency.

15. GPS Coordinates of Field:

16. Expected Output

1. Development of a validated integrated phosphorus-management strategy combining appropriate P placement, reduced mineral-P application, FYM and PSB for calcareous rice-based cropping systems.
2. Generation of a three-year dataset on crop growth, canopy characteristics, root development, yield, nutrient uptake, P-use efficiency and residual-P utilization under contrasting cropping and tillage systems.
3. Quantification of treatment-induced changes in Olsen P, soil-solution P and different soil-P fractions, particularly labile and Ca-associated pools.
4. Quantification of changes in soil physical condition and P stratification under conventional versus reduced/zero tillage with residue retention.
5. Determination of the contribution of soil biological processes, including microbial biomass P, phosphatase activity and PSB populations, to P mobilization.

6. Development of crop-wise, annual and cumulative phosphorus budgets for the different management systems.
7. Identification of a P-management treatment capable of reducing mineral-P requirement while maintaining productivity and profitability.
8. Preparation of farmer-ready recommendations, technical bulletins, research publications and extension material for calcareous soils of North Bihar.

17. Expected Outcome

- Improved phosphorus availability and P-use efficiency in calcareous soils.
- Reduced dependence on mineral phosphorus fertilizer.
- Greater utilization of accumulated/legacy soil phosphorus.
- Improved soil physical condition, aggregation and biological activity under suitable tillage-residue management.
- Better synchronization between root development, soil P supply and crop P demand.
- Sustainable productivity of rice–wheat–mungbean and rice–maize–mungbean cropping systems.
- Lower fertilizer expenditure and improved farm profitability.
- Generation of a scientifically validated P-management recommendation suitable for extension through ICAR–MGIFRI and KVKs.
- Improved nutrient-use efficiency and reduced risk of long-term P accumulation in agricultural soils.

18. History of the Experimental Plot

Item	Information
(a) When the field was developed	
(b) Crops cultivated season-wise	Rice-Wheat/Maize-Green gram
(c) Soil type	Fine Loamy Mixed Hyperthermic Calcareous Fluventic Haplustepts
(d) Soil pH, EC and OC	pH-8.21-8.32, EC-0.24-0.27 dsm^{-1}, OC: 0.67%
(e) Soil depth	More than 100cm
(f) Soil NPK and micronutrient status	
(g) Common pests and diseases	