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*Research Article*

# Yield assessment of rice-black gram, rice-maize and rice-groundnut sequential cropping system influenced by rice establishment methods and nutrient management practices in the dry tract of the Southern zone of Tamil Nadu, India

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**Abstract**
Integrated nutrient management (INM) practices and suitable cropping systems are an effective and promising way for enhancing crop productivity. However, the impact of proper INM practices and cultivation methods in rice cropping systems in dry tracts remains unclear. The field study evaluated the suitable cropping system under different rice establishment methods with INM practices in a sequential cropping system( rice-black gram, rice-maize, and rice-groundnut). Treatments were designed as two rice establishment methods [Direct Seeded Rice (DSR) and Transplanted Rice (TPR)] and five INM practices [RDF-Recommended Dose of Fertilizer (120:40:40 kg NPK $ha^{-1}$) alone, RDF + Poultry manure compost @ 5 t $ha^{-1}$, RDF+ Coir pith compost @ 5 t $ha^{-1}$, RDF+ Green manure @ 6.25 t $ha^{-1}$ and RDF-Green leaf manure @ 6.25 t $ha^{-1}$]. TPR with the INM practice of RDF + poultry manure compost @ 5 t $ha^{-1}$ recorded maximum productive tillers $m^{-2}$ (351), number of filled grains $panicle^{-1}$ (130.2), grain yield (6709 kg $ha^{-1}$) and straw yield (9015 kg $ha^{-1}$) of rice. Rice fallow crops (black gram, maize and groundnut) recorded 10 – 24,10-18 and 10 - 21 % higher values of yield components and yield, respectively, in DSR with INM treatment of RDF + Green manure @ 6.25 t $ha^{-1}$ . Thus, RDF plus green manure or poultry manure application is an apt INM practice for a rice-based sequential cropping system under DSR, and the rice-black gram is an economical and sustainable cropping system for dry tracts of the southern zone of Tamil Nadu.

**Keywords:** Black gram, DSR, INM, Organic manures, Rice, Sequential cropping system, Yield

## INTRODUCTION

Rice is an important and extensively cultivated crop worldwide, feeding more than half of the world's population. It is the world's second most widely consumed cereal next to wheat (Shreehail *et al*. 2020). In Asia, rice constitutes an important annual crop rotation. Continuous mono-cropping of rice has resulted in a decline of yield output due to multiple nutrient deficiencies and worsening soil physico-chemical properties (Mangaraj *et al*. 2022). To avoid such multi-nutrient deficiencies, suitable cropping can pave an alternate path for nutrient management and to sustain soil health. A rice-based cropping system can be described as a mix of farming practices comprising rice as the major crop followed by the subsequent cultivation of other crops (Quion and Cagasan, 2021). Rice-based cropping systems are the main agricultural production systems catering to food demands in most South Asian countries. Several intensive rice-based cropping systems (rice-wheat, rice-rice, rice-legumes, rice-sugarbeet, rice-maize, rice-jute etc.) have been practiced by farmers in India (Deep *et al*., 2018). In recent years, double and triple cropping systems have had more focusing points for increasing farmers' income, so diversification and intensification of cropping systems with good remuneration. Essential crops like pulses, oilseeds and vegetables have great scope to generate maximum net profit under a rice-based cropping system (Kalita *et al*., 2020). Rice-based cropping systems form an integral part of agriculture in Tamil Nadu (Porpavai *et al*., 2011). Rice occupies a major area of cultivation in Sivaganga district of Tamil Nadu. The success of rice crops depends on distribution and failure of rainfall. In some parts of the Sivaganga district, rice is grown with "semi dry rice" method, wherein the crop completes a part of its life period in water-logged or flooded conditions. Recently, the Sivaganga district has received a good amount of rainfall to grow crops and the excess rainfall is stored in the ponds or any water reservoir and utilised for succeeding crops after rice. So, keeping in view, there is a need for the identification of a suitable rice-based cropping sequence to enhance the system productivity and profitability of the cropping intensity of the southern zone. This evidence paves the way to evaluate the suitable cropping system from the following systems, *viz.,* rice-black gram, rice-maize and rice-groundnut, along with appropriate nutrient management practices to increase the system's yield potential in a sustainable manner. In the case of sequential crops, pulses are considered inseparable following crops among the farmers, which deals with limited risk with a high fetchable market price. Similarly, maize and groundnuts have also enlightened dramatic prices for their produce and widely triggered the cultivation interest among the farmers due to their less maintenance and cost-effective value-added products interlinked in the South Indian menu for around the year. Although during the last three decades fertilizer practices have played a dominant role in rice-based cropping systems; fertilizer application is of paramount importance for its role in growth and development of the crop (Penuelas *et al.* 2023) . Whereas, intensive agriculture involving exhaustive high-yielding varieties of rice and other crops, has led to heavy withdrawal of nutrients from the soil, imbalanced and indiscriminate use of chemical fertilizers has resulted in the deterioration of soil quality in the marginal soils (Meena *et al*., 2019).

Deterioration of soil properties, inadequate crop and nutrient management, and adverse changes in climatic parameters are considered the basic causes of yield declines or stagnation. Hence, it is time to pay serious attention to nutrient management and sustainable soil health. The integrated use of organic manures and inorganic fertilizers is expected to complement the nutritional needs of plants; thus, it can increase and stimulate plant growth, yield and long-term soil productivity (Sunarpi *et al*., 2021). There is a vast scope for increasing nutrient supply through organic manures and adopting a proper cropping system, which together can contribute significantly to the soil nutrient pool. The high cost of fossil fuel-based fertilizers and unstable crop production call for substituting part of the inorganic fertilizers with locally available low-cost organic sources like FYM, green manuring and vermicompost in an integrated manner is essential for sustainable production (Puli *et al*., 2017). Integrated Nutrient Management (INM), a agronomic system, uses organic and inorganic fertilizer sources. INM's main objective is to use as little chemical fertilizer as possible. It also helps to boost revenue and reduce environmental risks (Kumar *et al*., 2023).

Integrated nutrient management (INM) is the most effective method of maintaining healthy and sustainable soil systems while increasing crop productivity. In general, using various INM practices to increase the production of rice-based cropping systems has a great potential to significantly benefit system production, especially rice-based cropping systems yields and promising towards meeting the global food demand (Kumar *et al*., 2021). Keeping all these sustainable ways in view, the present study was carried out to identify the suitable rice establishment methods as well as best INM practices for rice-based cropping systems to assess the suitable-cum-sustainable cropping system for the dry tracts of the southern zone of Tamil Nadu, especially, Sivaganga district which promise to provide a better system yield performance with amenable INM practices in a sustainable way.

## MATERIALS AND METHODS

Field experiments were conducted during the Late *samba* season (September to January) for rice followed by maize, black gram and groundnut cropping system in *Navarai* season (January to May) of 2021-2022 at Sadurvedamangalam village (Latitude: 9.86°N ; Longitude: 78.48° E, Singampunai taluk, Sivaganga district, Tamil Nadu (Fig.1) to assess the influence of different Integrated Nutrient Management (INM) practices on certain promising rice-based cropping systems *viz.,* rice - maize, rice - black gram and rice – groundnut. The details of the experimental site of the study are presented in Table 1.

The cultivation of crops in areas where average annual rainfall is less than 750 mm per annum is called dry farming (dry tract). The average rainfall of 40.5 mm was during the cropping period from Sep 2021 to May 2022. The maximum temperature during the cropping period ranged from 27.3°C to 40.4°C with a mean of 33.85°C, the minimum temperature ranged from 19.7°C to 28.7°C with a mean of 24.2°C and the relative humidity ranged from 75.00 to 94.86 %t with a mean of 84.93 per cent (Table 7). A composite soil sample was collected (at a depth of 0-30 cm) air dried, processed and tested for physico-chemical properties. The soil was subject to mechanical analysis and classified as sandy clay loam in texture as per the analytical report pH 7.4, electrical conductivity 0.39 dS $m^{-1}$, low available nitrogen (203.6 kg $ha^{-1}$), medium available phosphorus (16.4 kg $ha^{-1}$), high available potash (284.4 kg $ha^{-1}$) and organic carbon of (0.36%). The experiment was carried out in a factorial randomized block design (FRBD) and replicated thrice with ten treatments. The treatments were Factor A-Two establishment methods ($A_1$-Direct Seeded Rice (DSR) and $A_2$-Transplanted Rice (TPR)) and Factor B- Five INM practices ($B_1$- RDF-Recommended Dose of Fertilizer (120:40:40 kg N, $P_2O_5$ and $K_2O$ $ha^{-1}$) alone, $B_2$- RDF + Poultry manure compost @ 5 t $ha^{-1}$, $B_3$- RDF+ Composed coir pith @ 5 t $ha^{-1}$, $B_4$- RDF+ Green manure (Daincha) @ 6.25 t $ha^{-1}$, and $B_5$- RDF + Green leaf manure @ 6.25 t $ha^{-1}$).

**Crop management practices for rice**

**Nursery preparation**

The nursery field was thoroughly ploughed, puddled to a fine colloidal condition, levelled and then irrigated. The seedbed was prepared along with suitable irrigation and drainage channels. Basal application of diammonium phosphate (DAP) was applied @ 2 kg $cent^{-1}$. An appropriate water column was maintained till sufficient germination was noticed. After that, 2.5 cm of water column was maintained throughout the nursery period. The seeds of rice *cv.* CO 51 were soaked in water for 12 hours, and the sprouted seeds were spread evenly in the prepared seedbed.

**Main field preparation and fertilization**

The main field was thoroughly ploughed, puddled well and levelled unanimously. The treatment plots were laid out with a dimension of 16.0 × 4.0 m, randomized and allotted as per the treatment schedule. After the nursery period, the seedling was transplanted into the main field with a spacing of 15 × 10 cm for the transplanting method of establishment whereas directly pre-sprouted seeds were sown in the main field for direct sown rice establishment method.

For fertilization as per the treatment schedule, appropriate sources of organic manures *viz.,* poultry manure compost @ 5 t $ha^{-1}$ was, obtained from a poultry farm at Ariviyur Kalappur village (which is near the experimental field), composted coir pith @ 5 t $ha^{-1}$ was obtained from the coir pith industry at Sadurvedamangalam (location of the experimental site), Green manure (Daincha) @ 6.25 t $ha^{-1}$. The seeds were obtained from a fertilizer shop, Singampunari (near the experimental site), and green leaf manure @ 6.25 t $ha^{-1}$ was collected from in and around the experimental site of the farmer's own fields. These manures were applied basally and incorporated along with Azospirillum and phosphobacteria @ 2 kg $ha^{-1}$. Nutrient schedule of 120:40:40 kg N, $P_2O_5$ and $K_2O$ $ha^{-1}$ (RDF) was supplemented through urea (46 % N), DAP (18 % N and 46 % $P_2O_5$) and muriate of potash (60 % $K_2O$), respectively. Half of the recommended nitrogen and potash and the entire dose of phosphorus were applied basally as per the treatment schedule. The remaining dose of nitrogen and potash were applied into two equal splits as top dressing one at the maximum tillering stage and another at the panicle initiation stage. Zinc sulphate was applied as basal @ 25 kg $ha^{-1}$. The crop biometric observations of yield attributes such as the number of productive tillers $m^{-2}$, number of filled grains $panicle^{-1}$, grain yield, and straw yield were recorded. The nutrient content (nitrogen) in grain and straw was determined by the micro-Kjeldahl di-acid digestion method (Ma and Zuazaga,1942). Nutrient uptake was calculated by multiplying nutrient content with respective dry weight and expressed in kg $ha^{-1}$.

**Crop management Practices for Sequential crops (Black gram, maize, and groundnut)**

Immediately after harvesting the rice crop, the succeeding crops in the cropping system, *viz.,* maize, black gram and groundnut seeds, were dibbled in line sowing with taking advantage of moisture availability in the field. Each rice sown plot was carefully divided into a dimension of 16m x 4m for maize, black gram and groundnut crops. After properly establishing of each crop, a convenient layout like ridges and furrows for maize was prepared. As per the nutrient concern, no separate manure/fertilizer was applied to the crops in the sequential cropping system except 2% DAP spray @ knee high stage of maize, pre-flowering stage of black gram and the peg formation stage of groundnut . The biometric observations of yield attributes such as; number of pods $plant^{-1}$ number of seeds $pod^{-1}$, test weight seed yield and haulm yield for black gram; number of grain row $cob^{-1}$ , number of grains $row^{-1}$, total grains $cob^{-1}$, test weight , grain yield and stover yield for maize; and number of pods $plant^{-1}$ ,shelling percentage, test weight, pod yield , kernel yield and haulm yield for groundnut were recorded individually.

**Statistical analysis**

The experimental data were statistically analysed as suggested by Gomez and Gomez, (1976). And the significance of the difference between the means of the treatments, critical difference (CD) was calculated at the 5% probability level.

**Table 1.** Geographical and agro climatic characteristics of the study area

| **Site characteristics*** | |
|---|---|
| District | Sivaganga (Sadurvedamangalam village) |
| Latitude and Longitude | 9˚43' and 10˚2'N Latitude and 77˚47' and 78˚ 49'E Longitude |
| Agro-climatic zone | Southern zone |
| Mean Sea Level | 102 mts |
| Average rainfall | 931 mm |
| Major soils | Red soil, loamy and sandy clay loam |
| Major crops grown | Paddy, groundnut, black gram, coconut, sugarcane, mango, banana, guava, jack, sapota and anola |

**Fig. 1.** *Geographical location of experimental site (Village name: Sadurvedamangalam ; Taluk: Singampunari ; District: Sivaganga ;Latitude: 9.86˚ N ;Longitude: 78.48˚ E)*

## RESULTS AND DISCUSSION

### Yield parameters and yield of rice

Based on the ANOVA, the p- p-values of main treatments and sub treatments and their interaction on yield parameters and yield are shown in Table 2. Among the rice establishment methods, the transplanted rice (TPR) ($A_2$) method registered higher number of productive tillers $m^{-2}$ (329), number of filled grains panicle$^{-1}$ (124.28), grain yield (5769 kg ha$^{-1}$), straw yield (7974 kg ha$^{-1}$), test weight (16.58 g) and harvest index (41.92%). This could be attributed to the quality of rice seedlings in the nursery before transplanting into rice fields is commonly good; plants that have already developed roots and other systems are stronger, making them less vulnerable to outside conditions (Hindersah *et al*., 2022). Further, in rice, less crop weed competition was observed due to TPR seedlings having a competitive advantage over early weeds in the early vegetative growth stage. Moreover, early weeds in TPR can be efficiently controlled by flooding when compared to direct-seeded rice (DSR) (Nazir *et al*., 2020). In addition to that, it maintains uniform stand and optimum population. It provides an ideal rhizosphere environment that might have contributed to higher nutrient uptake, which resulted in the production of greater source and efficient translocation of photosynthates into the larger sink as indicated by higher yield attributes (Bhardwaj *et al*., 2018). Whereas the lower number of productive tillers $m^{-2}$ (315), number of filled grains panicle$^{-1}$ (122.71), grain yield (5498 kg ha$^{-1}$), straw yield (7677 kg ha$^{-1}$), test weight (16.54 g) and harvest index (41.66 %) were registered in direct seeding method ($A_1$) of rice establishment. DSR yield was 12% lower than that of TPR, mainly due to fewer spikelets per panicle. This might be attributed to heavy shading before the heading, which reduced the hull size in DSR due to its higher plant density than TPR (Xu *et al*., 2019).

Among the different INM practices, the higher number of productive tillers $m^{-2}$ (364), number of filled grains panicle$^{-1}$ (129), grain yield (6530 kg ha$^{-1}$), straw yield (8824 kg ha$^{-1}$), test weight (16.73 g) and harvest index (42.53 %) recorded in RDF + Poultry manure compost @ 5 t ha$^{-1}$. The higher yield attributes and yield might be due to higher levels of inorganic fertilizers, which have increased photosynthesis and enzymes responsible for transforming energy, carbohydrates, fat metabolism and plant respiration (Yadav *et al*., 2019). Poultry manure is an excellent organic fertilizer, containing high nitrogen, phosphorus, potassium and other essential nutrients. It also indicated that poultry manure more readily supplies P to plants than other organic manure sources (Babu *et al*., 2021). INM improve yield attributes due to the instantaneous and rapid supply of nutrient through chemical fertilizers and steady supply through mineralization of poultry manure (PM) for prolonged period (Neti *et al*., 2022). Integrated application of PM with inorganic nutrients improved the soil's physical, chemical and biological environment, which encouraged the proliferation of roots, resulting in more absorption of water and nutrients from a larger area and depth, resulting in a higher grain yield (Rahman *et al*., 2016). The least number of productive tillers $m^{-2}$ (275), number of filled grains panicle$^{-1}$ (116.63), grain yield (4563 kg ha$^{-1}$), straw yield (6638 kg ha$^{-1}$), test weight (16.37 g) and harvest index (40.73 %) was observed under RDF-Recommended Dose of Fertilizer (120:40:40 kg N, $P_2O_5$ and $K_2O$ ha$^{-1}$) alone ($B_1$) due to

**Table 2.** Effect of establishment methods and INM practices on yield parameters and yield of rice

| Parameters / Treatments | Productive tillers $m^{-2}$ | | | Number of filled grains $panicle^{-1}$ | | | Grain yield ($kg\ ha^{-1}$) | | | Straw yield ($kg\ ha^{-1}$) | | | Test weight (g) | | | *Harvest index (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A / B | $A_1$ | $A_2$ | | $A_1$ | $A_2$ | | $A_1$ | $A_2$ | | $A_1$ | $A_2$ | | $A_1$ | $A_2$ | | $A_1$ | $A_2$ |
| $B_1$ | 266 | 283 | | 115.41 | 117.84 | | 4367 | 4758 | | 6437 | 6839 | | 16.35 | 16.39 | | 40.42 | 41.03 |
| $B_2$ | 356 | 372 | | 127.83 | 130.17 | | 6350 | 6709 | | 8632 | 9015 | | 16.68 | 16.71 | | 42.38 | 42.67 |
| $B_3$ | 298 | 311 | | 120.17 | 122.59 | | 5116 | 5457 | | 7230 | 7615 | | 16.46 | 16.53 | | 41.44 | 41.75 |
| $B_4$ | 330 | 342 | | 125.15 | 125.46 | | 5855 | 6006 | | 8071 | 8252 | | 16.60 | 16.64 | | 42.04 | 42.12 |
| $B_5$ | 327 | 336 | | 124.98 | 125.32 | | 5802 | 5914 | | 8013 | 8149 | | 16.59 | 16.62 | | 42.00 | 42.05 |
| | A | B | A x B | A | B | A x B | A | B | A x B | A | B | A x B | A | B | A x B | | |
| S.Ed. | 1.86 | 2.94 | 4.16 | 0.47 | 0.75 | 1.06 | 69 | 110 | 155 | 80 | 126 | 178 | 0.10 | 0.16 | 0.23 | *Statistically not analysed | |
| CD(p=0.05) | 3.90 | 6.14 | 8.73 | 1.00 | 1.58 | 2.23 | 146 | 230 | 326 | 167 | 264 | 374 | NS | NS | NS | | |

$A_1$-Direct seeded rice (DSR), $A_2$-Transplanted rice (TPR), $B_1$-Recommended dose of fertilizer (120:40:40 kg N, $P_2O_5$ and $K_2O$ $ha^{-1}$), $B_2$- RDF+ Poultry manure compost @ 5 t $ha^{-1}$, $B_3$- Coir pith compost @ 5 t $ha^{-1}$, $B_4$-Green manure (Daincha-*Sesbania aculeata*) @ 6.25 t $ha^{-1}$, $B_5$- RDF + Green leaf manure (Neem-*Azadirachta indica*) @ 6.25 t $ha^{-1}$

non-availability of adequate supply of nutrients especially nitrogen and phosphorus to the crop which was evident from recording low yield attributing parameters and yield.

Interaction effects of rice establishment methods and nutrient management practices were found to be significant. The treatment combination of transplanted rice + RDF+ Poultry manure compost @ 5 t $ha^{-1}$ ($A_2B_2$) noticed with higher number of productive tillers $m^{-2}$ (372), number of filled grains $panicle^{-1}$ (130.17), grain yield (6709 kg $ha^{-1}$), straw yield (9015 kg $ha^{-1}$), test weight (16.71g) and harvest index (42.67 %) and nutrient uptake (66.42 kg $ha^{-1}$) for grain and (84.74 kg $ha^{-1}$) for straw. The minimum number of productive tillers $m^{-2}$ (266), number of filled grains $panicle^{-1}$ (115.41), grain yield (4367 kg $ha^{-1}$), straw yield (6437 kg $ha^{-1}$), test weight (16.35 g) and harvest index (40.42 %) were recorded in RDF alone applied plots in direct seeded rice ($A_1B_1$)

**Nitrogen uptake**

Nitrogen uptake is an important factor for rice growth and development thus its availability directly affects rice yields. Among the rice establishment methods, higher nitrogen uptake of 56.46 kg $ha^{-1}$ and 73.02 kg $ha^{-1}$ in grain and straw were recorded in transplanted rice ($A_2$) establishment method (Table 3). This might be due to puddling in transplanted rice limits percolating water in the field and retaining a saturated soil profile, which inhibits nitrification (preventing oxidation of $NH_4^{\ +}$). So, leaching loss would have been checked, and more nitrogen might have been retained in ammonical form, leading to more nitrogen availability under transplanted conditions and favouring higher nitrogen uptake (Thapliyal *et al*., 2020). Lower nutrient uptake of (44.26 kg $ha^{-1}$) for grain and (58.13 kg $ha^{-1}$) for straw was recorded in the direct seeding method ($A_1$) of rice establishment, where the said N loss may not be contained by soil conditions significantly. Among the different INM practices, a higher nitrogen uptake of 64.65 kg $ha^{-1}$ in grain and 82.51 kg $ha^{-1}$ in straw was recorded in RDF + Poultry manure compost @ 5 t $ha^{-1}$ treatment (Table 3). This might be due to added fertilizers, FYM, green manuring, and poultry manure as a better availability source of N in soil to rice crop. And lower nutrient uptake (44.26 kg $ha^{-1}$) for grain and (58.13 kg $ha^{-1}$) for straw due to poor availability and higher loss of nutrients under RDF alone ($B_1$) (Puli *et al*., 2016). When considering the interaction effect (found to be significant) on N uptake, higher values of 66.42 kg $ha^{-1}$ and 84.77 kg $ha^{-1}$ in grain and straw were recorded (respectively) under TPR with RDF plus poultry manure applied treatment, whereas the lower N uptake values (42.36 & 56.07 kg $ha^{-1}$) were recorded in Direct Seeded Rice (DSR) + RDF (120:40:40 kg N, $P_2O_5$ and $K_2O$ $ha^{-1}$) alone ($A_1B_1$).

**Table 3.** Effect of rice establishment methods and INM practices on nutrient uptake of rice (kg $ha^{-1}$)

| | **N uptake (Grain)** | | | **N uptake (Straw)** | | |
|---|---|---|---|---|---|---|
| Factors | $A_1$ | | $A_2$ | $A_1$ | | $A_2$ |
| $B_1$ | 42.36 | | 46.15 | 56.07 | | 60.18 |
| $B_2$ | 62.87 | | 66.42 | 80.28 | | 84.74 |
| $B_3$ | 49.63 | | 52.93 | 64.35 | | 69.30 |
| $B_4$ | 57.38 | | 58.86 | 74.25 | | 75.92 |
| $B_5$ | 56.86 | | 57.96 | 73.72 | | 74.97 |
| Mean | 53.82 | | 56.46 | 69.73 | | 73.02 |
| | A | B | A x B | A | B | A x B |
| S.Ed. | 0.70 | 1.11 | 1.58 | 0.91 | 1.44 | 2.04 |
| CD(p=0.05) | 1.48 | 2.34 | 3.31 | 1.92 | 3.03 | 4.28 |

$A_1$-Direct seeded rice (DSR), $A_2$-Transplanted rice (TPR), $B_1$-Recommended dose of fertilizer (120:40:40 kg N, $P_2O_5$ and $K_2O$ $ha^{-1}$), $B_2$- RDF+ Poultry manure compost @ 5 t $ha^{-1}$, $B_3$- Coir pith compost @ 5 t $ha^{-1}$, $B_4$-Green manure (Daincha-*Sesbania aculeata*) @ 6.25 t $ha^{-1}$, $B_5$- RDF + Green leaf manure (Neem-*Azadirachta indica*) @ 6.25 t $ha^{-1}$

**Rice fallow black gram - Yield parameters and yield**

The residual effect of different integrated nutrient management practices under rice establishment methods (DSR and TPR) practiced for rice crop influenced the yield of black gram significantly (Table 4). The number of pods $plant^{-1}$ (12.23), number of seeds $pod^{-1}$ (4.39), seed yield (475 kg $ha^{-1}$), haulm yield (969 kg $ha^{-1}$), test weight (4.38 g) and harvest index (32.70%) were significantly higher under direct seeded rice ($A_1$) establishment method. The residual effect of rice establishment methods influenced the seed and haulm yield because earlier maturity of DSR as compared to TPR fits this well for different cropping systems. DSR is more cost-effective and environmentally friendly than the puddled transplanted rice system (Jat *et al*., 2022). Significantly minimum number of pods $plant^{-1}$ (11.91), number of seeds $pod^{-1}$(4.12), seed yield (417 kg $ha^{-1}$), haulm yield (887 kg $ha^{-1}$), test weight (4.34 g) and harvest index (31.79%) were observed in transplanted method ($A_2$) of establishment due to greater compaction of puddle soil under transplanting method and its carry over effect on succeeding crop (Bastola, 2020).

Among the residual effect of different integrated nutrient management practices imposed on preceding rice crop on succeeding black gram seed and haulm yield (Table 4), the highest residual effect was registered by RDF + Green manure @ 6.5 t $ha^{-1}$ ($B_4$) and RDF+ Green leaf manure @ 6.5 t $ha^{-1}$ ($B_5$) obtained number of pods $plant^{-1}$ (13.15), number of seeds $pod^{-1}$(5.08), seed yield (579 kg $ha^{-1}$), haulm yield (1167 kg $ha^{-1}$), test weight (4.46 g) and harvest index (33.15%) of black gram. This could be attributed to the slow decomposition of organic manures, which might have released the nutrients slowly and increased the availability of more nutrients to the benefit of succeeding black gram. Green manuring might reduce the loss of mineral N by leaching and decrease ammonia volatilization losses (Thiagarajan and Somasundaram, 2019). The lower number of pods $plant^{-1}$ (10.45), number of seeds $pod^{-1}$ (3.21), seed yield (280 kg $ha^{-1}$), haulm yield (632 kg $ha^{-1}$), test weight (4.24 g) and harvest index (30.62%) of black gram were recorded in RDF-Recommended Dose of Fertilizer (120:40:40 kg N, $P_2O_5$ and $K_2O$ $ha^{-1}$) alone ($B_1$) applied treatment. The recommended dose of NPK fertilizers alone does not sustain soil productivity under continuous intensive cropping, so only a single application of manures mediates less fertility (Aruna *et al*., 2019).

Residual effects of integrated nutrient management practices and rice establishment methods show significant interaction effects on black gram yield attributes and yield. In interaction, higher number of pods $plant^{-1}$ (13.21), number of seeds $pod^{-1}$ (5.21), seed yield (615 kg $ha^{-1}$), haulm yield (1208 kg $ha^{-1}$), test weight (4.49 g) and harvest index (33.74%) was observed in Direct Seeded Rice + RDF+ Green manure @ 6.25 t $ha^{-1}$ ($A_1B_4$), it was on par with three treatments such as Direct Seeded Rice + RDF + Green leaf manure @ 6.25 t $ha^{-1}$ ($A_1B_5$), Transplanted Rice + RDF + Green manure @ 6.25 t $ha^{-1}$ ($A_2B_4$) and Transplanted Rice + RDF + Green leaf manure @ 6.25 t $ha^{-1}$($A_2B_5$). The lower number of pods $plant^{-1}$ (10.24), number of seeds $pod^{-1}$ (3.09), seed yield (280 kg $ha^{-1}$), haulm yield (632 kg $ha^{-1}$), test weight (4.22 g) and harvest index (30.62 %) were found in TPR+ RDF-Recommended Dose of Fertilizer (120:40:40 kg N, $P_2O_5$ and $K_2O$ $ha^{-1}$) alone ($A_2B_1$) treatment due to less or no residual effect on succeeding crop i.e. without organics RDF alone may fail to maintain the soil health significantly.

**Rice fallow maize-yield parameters and yield**

The residual effect of different integrated nutrient management practices under rice establishment methods (DSR and TPR) practiced for rice crops significantly influenced the yield parameters and yield of maize (Table 5). The number of grain row $cob^{-1}$ (10.25), number of grains $row^{-1}$ (11.27), total grains $cob^{-1}$ (127.12), grain yield (2128 kg $ha^{-1}$), stover yield (4275 kg $ha^{-1}$), test weight (24.39 g) and harvest index (33.19 %) were

**Table 4.** Residual effect of rice establishment methods and INM practices on rice-black gram yield parameters and yield

| A/B | Number of pods plant$^{-1}$ | | | Number of seeds pod$^{-1}$ | | | Seed yield (kg ha$^{-1}$) | | | Haulm yield (kg ha$^{-1}$) | | | Test weight (g) | | | *Harvest index (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $A_1$ | $A_2$ | | $A_1$ | $A_2$ | | $A_1$ | $A_2$ | | $A_1$ | $A_2$ | | $A_1$ | $A_2$ | | $A_1$ | $A_2$ |
| $B_1$ | 10.65 | 10.24 | | 3.32 | 3.09 | | 312 | 248 | | 673 | 591 | | 4.08 | 4.03 | | 31.68 | 29.56 |
| $B_2$ | 12.56 | 12.08 | | 4.50 | 4.21 | | 476 | 432 | | 997 | 906 | | 4.31 | 4.25 | | 32.32 | 32.29 |
| $B_3$ | 11.57 | 11.13 | | 3.87 | 3.60 | | 391 | 350 | | 823 | 738 | | 4.20 | 4.14 | | 32.21 | 32.17 |
| $B_4$ | 13.21 | 13.09 | | 5.21 | 4.94 | | 615 | 543 | | 1208 | 1125 | | 4.49 | 4.42 | | 33.74 | 32.55 |
| $B_5$ | 13.14 | 13.02 | | 5.06 | 4.77 | | 579 | 514 | | 1146 | 1074 | | 4.46 | 4.37 | | 33.57 | 32.37 |
| | A | B | A x B | A | B | A x B | A | B | A x B | A | B | A x B | A | B | A x B | | |
| S.Ed. | 0.08 | 0.13 | 0.18 | 0.04 | 0.06 | 0.09 | 8 | 12 | 18 | 13 | 21 | 30 | 0.09 | 0.15 | 0.21 | *Statistically not analysed | |
| CD(p=0.05) | 0.17 | 0.27 | 0.38 | 0.08 | 0.13 | 0.19 | 16 | 26 | 37 | 28 | 45 | 63 | NS | NS | NS | | |

$A_1$-Direct seeded rice (DSR), $A_2$-Transplanted rice (TPR), $B_1$-Recommended dose of fertilizer (120:40:40 kg N, $P_2O_5$ and $K_2O$ ha$^{-1}$), $B_2$- RDF+ Poultry manure compost @ 5 t ha$^{-1}$, $B_3$- Coir pith compost @ 5 t ha$^{-1}$, $B_4$-Green manure (Daincha-*Sesbania aculeata*) @ 6.25 t ha$^{-1}$, $B_5$- RDF + Green leaf manure (Neem-*Azadirachta indica*) @ 6.25 t ha$^{-1}$

**Table 5.** Residual effect of rice establishment methods and INM practices on rice-maize yield parameters and yield

| A / B | Number of grain row cob$^{-1}$ | | | Number of grains row$^{-1}$ | | | Total grains cob$^{-1}$ | | | Grain yield (kg ha$^{-1}$) | | | Stover yield (kg ha$^{-1}$) | | | Test weight (g) | | | *Harvest index (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $A_1$ | $A_2$ | | $A_1$ | $A_2$ | | $A_1$ | $A_2$ | | $A_1$ | $A_2$ | | $A_1$ | $A_2$ | | $A_1$ | $A_2$ | | $A_1$ | $A_2$ |
| $B_1$ | 8.42 | 7.74 | | 9.32 | 8.64 | | 86.89 | 74.61 | | 1634 | 1381 | | 3356 | 3087 | | 24.02 | 23.87 | | 32.75 | 30.91 |
| $B_2$ | 10.67 | 10.09 | | 11.69 | 11.08 | | 135.40 | 121.89 | | 2218 | 2072 | | 4439 | 4168 | | 24.39 | 24.25 | | 33.32 | 33.21 |
| $B_3$ | 9.53 | 8.98 | | 10.51 | 9.87 | | 109.69 | 97.61 | | 1914 | 1779 | | 3904 | 3631 | | 24.21 | 24.16 | | 32.90 | 32.88 |
| $B_4$ | 11.36 | 11.23 | | 12.47 | 12.26 | | 153.02 | 148.91 | | 2457 | 2385 | | 4875 | 4744 | | 24.68 | 24.60 | | 33.51 | 33.45 |
| $B_5$ | 11.28 | 11.21 | | 12.35 | 12.23 | | 150.59 | 148.31 | | 2415 | 2356 | | 4802 | 4703 | | 24.64 | 24.52 | | 33.46 | 33.38 |
| | A | B | A x B | A | B | A x B | A | B | A x B | A | B | A x B | A | B | A x B | A | B | A x B | | |
| S.Ed. | 0.07 | 0.11 | 0.16 | 0.11 | 0.17 | 0.24 | 1.61 | 2.54 | 3.59 | 27 | 43 | 60 | 44 | 70 | 99 | 0.22 | 0.36 | 0.50 | *Statistically not analysed | |
| CD(p=0.05) | 0.15 | 0.24 | 0.33 | 0.23 | 0.36 | 0.51 | 3.37 | 5.33 | 7.54 | 57 | 90 | 127 | 93 | 147 | 208 | NS | NS | NS | | |

$A_1$-Direct seeded rice (DSR), $A_2$-Transplanted rice (TPR), $B_1$-Recommended dose of fertilizer (120:40:40 kg N, $P_2O_5$ and $K_2O$ ha$^{-1}$), $B_2$- RDF+ Poultry manure compost @ 5 t ha$^{-1}$, $B_3$- Coir pith compost @ 5 t ha$^{-1}$, $B_4$-Green manure (Daincha-*Sesbania aculeata*) @ 6.25 t ha$^{-1}$, $B_5$- RDF + Green leaf manure (Neem-*Azadirachta indica*) @ 6.25 t ha$^{-1}$

significantly higher under direct seeded rice ($A_1$). This might be due to the quick establishment and earlier harvest than transplanted rice, consequently facilitating timely maize sowing and thus enhancing the sustainability of the rice-maize cropping system. Whereas the minimum number of grain row $cob^{-1}$ (9.85), number of grains $row^{-1}$ (10.82), total grains $cob^{-1}$ (118.27), grain yield (1995 kg $ha^{-1}$), stover yield (4067 kg $ha^{-1}$), test weight (24.28 g) and harvest index (32.77 %) were recorded in transplanted rice ($A_1$). Transplanting rice seedlings is a major established practice in most rice-growing areas. Although this practice is labour, water, and energy intensive and deteriorates the soil properties due to the formation of the compact hard soil surface, it is input-intensive. It degrades the soil system (Hargilas and Jat, 2016).

Among the residual effect of different integrated nutrient management practices imposed on preceding rice crop on maize grain and stover yield, the highest residual effect was registered by RDF + Green manure @ 6.5 t $ha^{-1}$ ($B_4$) and RDF + Green leaf manure @ 6.5 t $ha^{-1}$ ($B_5$) recorded higher number of grain row $cob^{-1}$ (11.30), number of grains $row^{-1}$ (12.37), total grains $cob^{-1}$ (150.97), grain yield (2421 kg $ha^{-1}$), stover yield (4810 kg $ha^{-1}$), test weight (24.64 g) and harvest index (33.48 %) (Table 5) of maize crop. Integrated use of organic sources and chemical fertilizer often leaves a substantial residual effect on succeeding crops in the system. The combined application of inorganic with organic like green manure increases yield attributes and yield of rice due to the continuous slow release of nutrients which have enabled extension of the leaf area duration thereby providing an opportunity time for plants to increase the photosynthetic rate, which in turn better source and sink relationship led to higher yield attributes of succeeding crop. The increase in yield with the combined application of organics and inorganics might be due to better and continuous availability of nutrients for plants (Mounika *et al*., 2018). A lower number of grain row $cob^{-1}$ (8.08), number of grains $row^{-1}$ (8.98), total grains $cob^{-1}$ (80.75), grain yield (1508 kg $ha^{-1}$), stover yield (3222 kg $ha^{-1}$), test weight (23.95 g) and harvest index (31.83 %) were recorded in Recommended Dose of Fertilizer (120:40:40 kg N, $P_2O_5$ and $K_2O$ $ha^{-1}$) alone ($B_1$)applied plots because inorganic fertilizer like urea which is the most available form of nitrogen when applied to rice is subjected to leaching and volatilization losses in addition to crop uptake (Deekshitha *et al*., 2021).

Residual effects of integrated nutrient management practices and rice establishment methods showed significant interaction effects on the yield attributes and yield of maize, i.e. a higher number of grain row $cob^{-1}$ (11.36), number of grains $row^{-1}$ (12.47), total grains $cob^{-1}$ (153.02), grain yield (2457 kg $ha^{-1}$), stover yield (4875 kg $ha^{-1}$), test weight (24.68 g) and harvest index (33.51

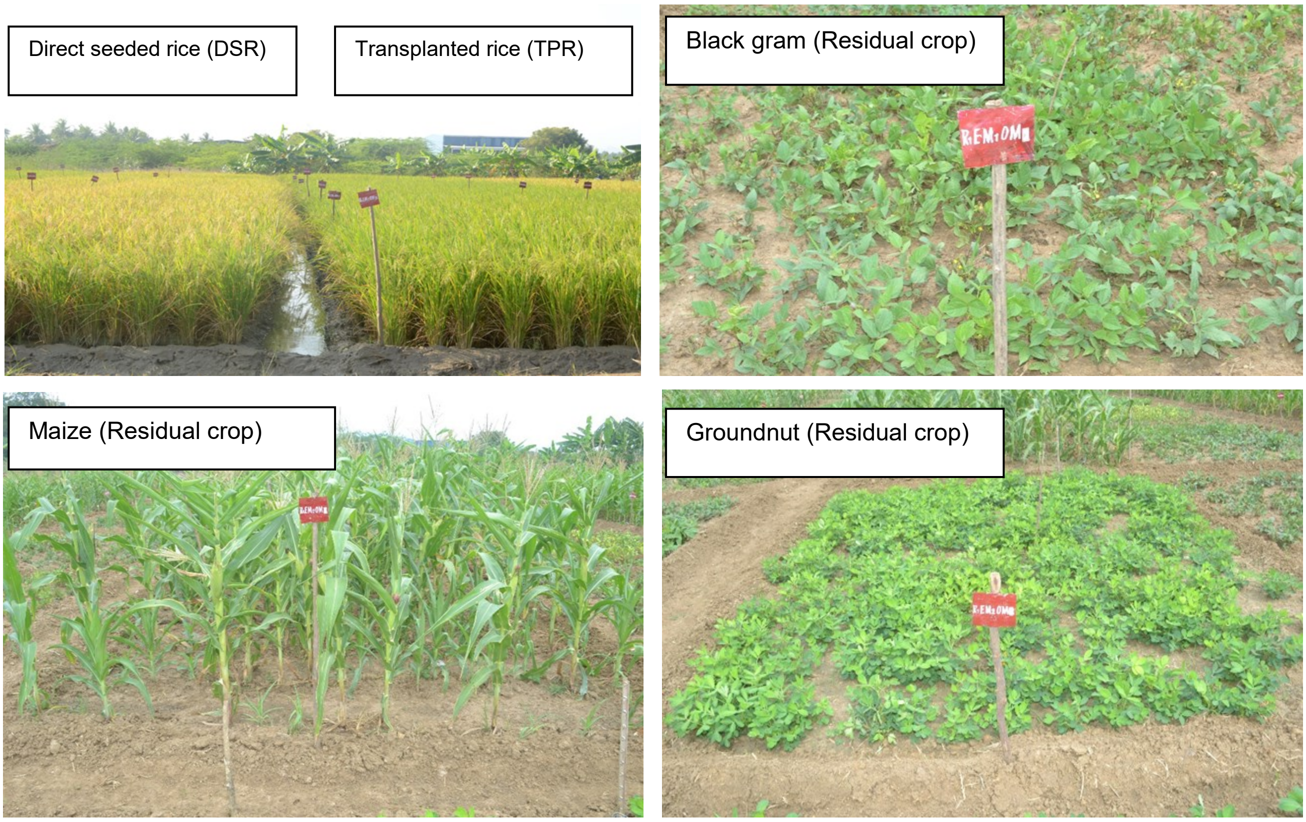


**Fig. 2.** *Experimental field view of rice under two establishment methods; Succeeding residual crops (black gram, maize and groundnut)*

**Table 6.** Residual effect of rice establishment methods and INM practices on rice-groundnut yield parameters and yield

| A / B | Number of pods plant$^{-1}$ | | Shelling percentage | | Pod yield (kg ha-1) | | Kernel yield (kg ha$^{-1}$) | | Haulm yield (kg ha$^{-1}$) | | Test weight (g) | | *Harvest index (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $A_1$ | $A_2$ | $A_1$ | $A_2$ | $A_1$ | $A_2$ | $A_1$ | $A_2$ | $A_1$ | $A_2$ | $A_1$ | $A_2$ | $A_1$ | $A_2$ |
| $B_1$ | 11.34 | 10.82 | 73.76 | 73.74 | 508 | 445 | 375 | 328 | 782 | 690 | 32.41 | 32.36 | 39.37 | 39.22 |
| $B_2$ | 13.29 | 12.87 | 74.18 | 74.03 | 769 | 701 | 570 | 519 | 1169 | 1067 | 32.95 | 32.78 | 39.68 | 39.65 |
| $B_3$ | 12.41 | 11.89 | 73.95 | 73.81 | 629 | 567 | 465 | 419 | 963 | 871 | 32.63 | 32.47 | 39.51 | 39.43 |
| $B_4$ | 14.13 | 13.98 | 74.32 | 74.25 | 914 | 856 | 679 | 636 | 1375 | 1296 | 33.31 | 33.13 | 39.93 | 39.78 |
| $B_5$ | 14.05 | 13.78 | 74.30 | 74.22 | 883 | 832 | 656 | 618 | 1334 | 1262 | 33.20 | 33.04 | 39.83 | 39.73 |

| | Number of pods plant$^{-1}$ | | | Shelling percentage | | | Pod yield (kg ha-1) | | | Kernel yield (kg ha$^{-1}$) | | | Haulm yield (kg ha$^{-1}$) | | | Test weight (g) | | | *Harvest index (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | A x B | A | B | A x B | A | B | A x B | A | B | A x B | A | B | A x B | A | B | A x B | |
| S.Ed. | 0.08 | 0.12 | 0.17 | 0.34 | 0.54 | 0.76 | 10 | 16 | 23 | 7 | 11 | 16 | 14 | 23 | 32 | 0.20 | 0.32 | 0.45 | *Statistically not analysed |
| CD(p=0.05) | 0.16 | 0.25 | 0.35 | NS | NS | NS | 21 | 34 | 48 | 15 | 23 | 33 | 30 | 47 | 67 | NS | NS | NS | |

$A_1$-Direct seeded rice (DSR), $A_2$-Transplanted rice (TPR), $B_1$-Recommended dose of fertilizer (120:40:40 kg N, $P_2O_5$ and $K_2O$ ha$^{-1}$), $B_2$- RDF+ Poultry manure compost @ 5 t ha$^{-1}$, $B_3$- Coir pith compost @ 5 t ha$^{-1}$, $B_4$-Green manure (Daincha-*Sesbania aculeata*) @ 6.25 t ha$^{-1}$, $B_5$- RDF + Green leaf manure (Neem-*Azadirachta indica*) @ 6.25 t ha$^{-1}$

%). In Direct Seeded Rice + RDF+ Green manure @ 6.25 t ha$^{-1}$ ($A_1B_4$) treatment, it was on par with three treatments such as Direct Seeded Rice + RDF + Green leaf manure @ 6.25 t ha$^{-1}$ ($A_1B_5$), Transplanted Rice + RDF + Green manure @ 6.25 t ha$^{-1}$ ($A_2B_4$) and Transplanted Rice + RDF + Green leaf manure @ 6.25 t ha$^{-1}$ ($A_2B_5$). But, lower number of grain row cob$^{-1}$ (7.74), number of grains row$^{-1}$ (8.64), total grains cob$^{-1}$ (74.61), grain yield (1381 kg ha$^{-1}$), stover yield (3087 kg ha$^{-1}$), test weight (23.87 g) and harvest index (30.91 %) were recorded in TPR+ RDF (120:40:40 kg N, $P_2O_5$ and $K_2O$ ha$^{-1}$) alone ($A_2B_1$) applied treatment.

**Rice fallow groundnut yield parameters and yield**

The residual effect of different integrated nutrient management practices under rice establishment methods (DSR and TPR) practiced for rice crops significantly influenced groundnut yield (Table 6). The residual effect of rice establishment methods reflected in the productivity by increasing the yield of groundnut. For instance, increased number of pods plant$^{-1}$ (13.04), shelling percentage (74.10), pod yield (741 kg ha$^{-1}$), kernel yield (549 kg ha$^{-1}$), haulm yield (1125 kg ha$^{-1}$), and harvest index (39.66 %) of groundnut was observed in direct seeded ($A_1$) method of establishment. Because the carryover effect of DSR favourably influenced the succeeding groundnut crop as compared to that grown after TPR. DSR favour the succeeding crop establishment because it might not have formed hard layers it help to easy root penetration for succeeding crop (Samant *et al.*, 2021). Lower number of pods plant $^{-1}$ (12.67), shelling percentage (74.01), pod yield (680 kg ha$^{-1}$), kernel yield (504 kg ha$^{-1}$), haulm yield (1037 kg ha$^{-1}$), test weight (32.76 g) and harvest index (39.56 %) of groundnut was recorded in transplanted method of rice establishment. In traditional puddled transplanted rice planting systems, puddling breaks capillary pores, destroys soil aggregates, disappears fine clay particles, and forms a hard pan at shallow depth. It will adversely affect the growth and yield of subsequent upland crops because of its adverse effect on soil physical properties, which include poor soil structure, suboptimal permeability in the lower layers and soil compaction (Bandyopadhyay *et al.*, 2019).

Among the different INM practices higher number of pods plant$^{-1}$ (14.06), shelling percentage (74.29), pod yield (885 kg ha$^{-1}$), kernel yield (658 kg ha$^{-1}$), haulm yield (1336 kg ha$^{-1}$), test weight (33.22 g) and harvest index (39.86 %) RDF + Green manure @ 6.5 t ha$^{-1}$ ($B_4$) and RDF + Green leaf manure @ 6.5 t ha$^{-1}$ ($B_5$) recorded highest yield attributes and yield of maize crop (Table 6). From the results, the present study observed that the integrated use of organic manures and inorganic fertilizers increased the productivity of rice-groundnut cropping systems. The efficiency of inorganic fertilizer is improved when used in conjunction with

**Table 7.** Weather data for the cropping period (Sep-May) during 2021-2022

| Months and Days | Standard Week No. | Mean temp ◦C | | Relative Humidity (%) | Rainfall (mm) | No. of rainy days |
|---|---|---|---|---|---|---|
| | | Max. | Min. | | | |
| 24 SEP-30 | 39 | 34.6 | 26.0 | 84.71 | 0.7 | 0 |
| OCT 01-O7 | 40 | 32.3 | 25.3 | 75.00 | 3.8 | 4 |
| 08-14 | 41 | 32.1 | 28.7 | 78.57 | 0.4 | 0 |
| 15-21 | 42 | 27.7 | 25.0 | 85.57 | 3.4 | 1 |
| 22-28 | 43 | 30.7 | 24.8 | 81.71 | 3.8 | 6 |
| 29-04 NOV | 44 | 27.6 | 23.4 | 85.86 | 4.4 | 5 |
| 05-11 | 45 | 27.3 | 22.8 | 89.00 | 3.3 | 3 |
| 12-18 | 46 | 31.0 | 23.3 | 82.57 | 3.7 | 3 |
| 19-25 | 47 | 29.9 | 23.4 | 89.42 | 4.4 | 5 |
| 26-02DEC | 48 | 28.6 | 22.7 | 87.71 | 3.3 | 3 |
| 03-09 | 49 | 29.7 | 23.4 | 94.86 | 2.1 | 3 |
| 10-16 | 50 | 29.6 | 22.1 | 92.28 | 0.6 | 0 |
| 17-23 | 51 | 30.0 | 20.4 | 89.28 | 0 | 0 |
| 24-31 | 52 | 30.2 | 19.7 | 87.00 | 0.2 | 0 |
| JAN 01-07 | 01 | 31.0 | 20.8 | 91.57 | 0.2 | 0 |
| 08-14 | 02 | 31.3 | 21.8 | 94.00 | 0.1 | 0 |
| 15-21 | 03 | 32.4 | 21.3 | 90.43 | 0.1 | 0 |
| 22-28 | 04 | 32.1 | 22.0 | 89.43 | 0.2 | 0 |
| 29-04 FEB | 05 | 32.4 | 21.4 | 87.00 | 0.0 | 0 |
| 05-11 | 06 | 34.0 | 21.4 | 83.28 | 0.0 | 0 |
| 12-18 | 07 | 33.3 | 21.8 | 84.71 | 0.1 | 0 |
| 19-25 | 08 | 36.1 | 22.3 | 85.43 | 0.0 | 0 |
| 26-04 MAR | 09 | 36.1 | 26.6 | 84.28 | 0.3 | 0 |
| 05-11 | 10 | 36.6 | 22.7 | 88.43 | 0.5 | 1 |
| 12-18 | 11 | 40.6 | 23.3 | 81.15 | 0 | 0 |
| 19-25 | 12 | 39.9 | 26.1 | 83.71 | 0.6 | 0 |
| 25-01 APR | 13 | 39.3 | 26.0 | 84.85 | 0.0 | 0 |
| 02-08 | 14 | 38.7 | 26.3 | 78.57 | 0.0 | 0 |
| 09-15 | 15 | 36.6 | 26.8 | 81.57 | 1.2 | 1 |
| 16-22 | 16 | 38.4 | 27.4 | 76.28 | 1.0 | 1 |
| 23-29 | 17 | 40.4 | 28.1 | 81.71 | 0.0 | 0 |
| 30-06 MAY | 18 | 40.3 | 28.3 | 81.14 | 0.9 | 1 |
| 07-13 | 19 | 38.4 | 27.7 | 82.28 | 0.4 | 0 |
| 14-20 | 20 | 34.1 | 26.7 | 80.43 | 0.6 | 1 |
| 21-27 | 21 | 38.3 | 27.1 | 76.71 | 0.2 | 0 |

green manures because green manure N is as efficient as fertilizer (urea) N in rice, high root density due to improved physical conditions of the soil enhances nutrient absorption capacity of the crop, thereby improving biological yield at a given level of fertilizer application. This may be due to the effect of green manure application enhanced the N content in soil pool (i.e. green manure typically has the potential to contribute about 70-80 kg of additional N ha$^{-1}$,( Ambrosano *et al.* 2013), which might have available for the growth and development of rice and subsequent groundnut crop, and similar results were reported by Samant *et al*., 2022. The lower number of pods plant$^{-1}$ (11.08), shelling percentage (73.75), pod yield (477 kg ha$^{-1}$), kernel yield (352 kg ha$^{-1}$), haulm yield (736 kg ha$^{-1}$), test weight (32.39 g) and harvest index (39.30 %) was noticed in TPR+ RDF-Recommended Dose of Fertilizer (120:40:40 kg N, $P_2O_5$ and $K_2O$ ha$^{-1}$) alone (B1) treatment. RDF alone causes low fertiliser consumption despite prominent nutrient deficiencies in succeeding crop (Mondal *et al*., 2019).

Thus, the residual effects of integrated nutrient management practices and rice establishment methods showed significant interaction effects on groundnut yield attributes and yield (Fig. 2). In interaction, a higher number of pods plant$^{-1}$ (14.13), shelling percentage (74.32), pod yield (914 kg ha$^{-1}$), kernel yield (679 kg ha$^{-1}$), haulm yield (1375 kg ha$^{-1}$), test weight (33.31 g) and harvest index (39.93 %) was observed in Direct Seeded Rice + RDF+ Green manure @ 6.25 t ha$^{-1}$ ($A_1B_4$) treatment, it was on par with three treatments such as Direct Seeded Rice + RDF + Green leaf manure @ 6.25 t ha$^{-1}$ ($A_1B_5$), Transplanted Rice + RDF + Green manure @ 6.25 t ha$^{-1}$ ($A_2B_4$) and Transplanted Rice+

RDF + Green leaf manure @ 6.25 t $ha^{-1}$ ($A_2B_5$). The lower number of pods $plant^{-1}$ (10.82), shelling percentage (73.74), pod yield (445 kg $ha^{-1}$), kernel yield (328 kg $ha^{-1}$), haulm yield (690 kg $ha^{-1}$), test weight (32.36 g) and harvest index (39.22 %) were recorded in TPR+ RDF-Recommended Dose of Fertilizer (120:40:40 kg N, $P_2O_5$ and $K_2O$ $ha^{-1}$) alone ($A_2B_1$) treatment.

## Conclusion

Rice establishment methods and integrated nutrient management practices positively affected rice-based sequential cropping systems' productivity. The combined application of RDF plus poultry manure @ 5 t $ha^{-1}$ INM practice had a higher response towards rice yield under the transplanted rice establishment method than direct seeded rice. However, the INM (RDF plus green manure @ 6.5 t $ha^{-1}$ ) implemented to rice under the direct seeded rice establishment method had a higher residual effect and thus more succeeding black gram, maize and groundnut yields over other INM practices. Among the sequential crops, it was identified that black gram was a more successful residual crop than maize and groundnut. Therefore, it is recommended that the rice–black gram sequential cropping system be the most suitable and sustainable cropping system in the study zone and conjoint application of RDF plus green manure or poultry manure could be the most viable and sustainable INM practice for selected dry tracts of southern zone Tamil Nadu. However, future research is needed to investigate the long-term effects of INM practices with other rice establishment methods and various rice and black gram varieties to appropriate future cropping windows for the present and future changing climatic scenario .

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## Conflict of interest

The authors declared that they have no conflicts of interest.

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