



RESEARCH ARTICLE

Quality, productivity and phosphorus use efficiency of groundnut under varied sowing dates and different sources of nitrogen and phosphorus

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Abstract

Timely sowing is one of the most important agronomic factors influencing the growth, development and yield potential of crops. Since the optimum sowing time, along with balanced nutrient management, plays a crucial role in maximising crop productivity, a field experiment was conducted at the Agricultural Research Station, Faculty of Agricultural Sciences, Siksha 'O' Anusandhan (SOA) Deemed to be University, Bhubaneswar, during the rabi-summer season of 2024 to determine the optimum sowing time and nitrogen-phosphorus (NP) combinations for groundnut. The experiment was laid out in a split-plot design, keeping three sowing dates in the main plot and six NP combinations in the subplots. All growth parameters, yield attributes, quality, yield and economic characters were highest when groundnut was sown on 17th January. Among NP combinations, with the use of farmyard manure (FYM), vermicompost (as a source of nitrogen (N) (in equivalent ratio), single superphosphate (SSP) and rock phosphate as a source of phosphorous (P) (in equivalent ratio) in addition to 7.5 kg ha⁻¹ phosphate-solubilising bacteria (PSB) as soil application was found to be the best in all aspects. Among the sowing-date treatments, the highest pod yield of 11.9 q ha⁻¹ and kernel yield of 8.4 q ha⁻¹ was recorded in D₂. Likewise, the highest oil content (49.8 %) and protein (20.3 %) content was also under this treatment. Among the NP combinations, treatment NP₄ produced the highest oil (51.6 %) and protein (22.6 %) contents in the kernels, with a pod yield of 12.2 q ha⁻¹. In both the sowing-date and NP combination treatments, the highest values of P recovery and P harvest index of 5.5 and 15.8, were found in D₂ and NP₄ respectively. Early sowing at 3rd SMW was found to be optimal for achieving maximum pod and kernel yield of groundnut as compare with the other sowing window in this part of Odisha. The use of rock phosphate and SSP in equal proportion and FYM and VC in equal proportions as a source of P and N respectively along with soil application of PSB (7.5 kg ha⁻¹) produced the highest pod and oil yield. This treatment was also found to be the best in terms of P use efficiency and P recovery when sown during 3rd standard meteorological week (SMW).

Keywords: groundnut; oil content; phosphate solubilising bacteria; pod yield; P-use efficiency; single super phosphate

Introduction

Groundnut, is one of the most important oilseed crops in India, is cultivated on about 10.23 Mha with a production of approximately 11.86 MT in of 2024 (1). It is mainly grown in the semi-arid tropics of Asia and Africa. Groundnut is widely cultivated under different environmental conditions from latitudes between 40° S and 40° N of the equator. It is grown successfully in the areas having an average rainfall ranging from 500–1200 mm as both a sole crop and an intercrop during the kharif and rabi seasons. Groundnut is a versatile crop containing 44–50 % vegetable oil and about 26 % vegetable protein. It is also a rich source of vitamins A, B and B₂ (2).

India ranks first in groundnut area and production; however, its productivity (1060 kg ha⁻¹) is considerably lower than that of the USA, China and several other countries. The foremost reason for this low yield in our country is that this 'energy-rich' crop is grown under

an 'energy-starved' situation. Among the various constraints, imbalanced nutrient management is the major reason for below-normal productivity. During the rabi-summer season limited irrigation water often leads to nutrient deficiencies resulting in low yield and this is perhaps the reason why agriculturists are not able to break the obstacle of the stagnated yield of groundnut.

The optimum time of sowing is the key factor to catch the potential yield of a given variety of groundnuts. Sowing the crop early may boost vegetative growth and development of reproductive parts, but increased foliage may increase susceptibility to various pests and diseases. On the other hand, delayed sowing may reduce the vegetative phase, decreases dry matter accumulation and assimilate partitioning to reproductive parts and thereby limiting the yield potential. Thus, the yield potential differs not only with varieties but also fluctuates under various agro-climatic conditions and sowing periods within the season. Previous

studies have shown that groundnut sown during the last week of December and the second week of January resulted in higher pod yield as it escaped higher temperature at flowering as compared to first week of February sown crop at Kharagpur (3). Therefore, selecting an appropriate sowing date is essential for synchronising critical crop growth stages with favourable atmospheric conditions and avoiding periods of stress.

Being a leguminous crop, groundnut needs a sufficient supply of nutrients, especially phosphorus (P) for root development, nodulation and high yields (4). Phosphorus is one of the predominant essential nutrients, next to nitrogen (N) and plays a vital role in crop growth and yield. It plays a decisive role in metabolic processes and serves structural, energetic and regulatory functions (5). With the increasing cost of chemical fertilisers, greater emphasis is now being placed on the use of biofertilisers. Biofertilisers are microbial inoculants made up of beneficial microorganisms that improve soil fertility and nutrient availability in both organic and inorganic agricultural systems, lowering cultivation costs and minimising environmental impact (6). Being microbial culture biofertilisers also have a beneficial effect on plant performance both directly and indirectly (7). Inoculation using rhizobial strains is one of the strategies employed to enhance symbiotic N fixation by legumes and hence improve yield in crop production system (8). Different rhizobium strains collected from different crops like Bambara groundnut, cowpea, or other groundnut varieties, have been reported to improve groundnut seed yield (9). Rhizobium inoculants promoted nutrient uptake and higher yield and also observed higher seed yield with yields being 16.5 % higher than the uninoculated control (10). Application of 20 kg N ha⁻¹ along with rhizobium and phosphate-solubilising bacteria (PSB) significantly increased the number of pods per plant, kernels per pod, seed index, seed yield and haulm yield which were superior among the treatments (11). Among biofertilisers, application of PSB, significantly increased nitrogen-phosphorus (NP) concentrations in both kernel and haulm (12). The groundnut forms root nodules that fix atmospheric N through biological N₂ fixation. Groundnut can contribute biologically fixed N to the soil and shares excess N with non-legumes, thereby enhancing the yield of cereals and other non-legume crops (13). Therefore, the present study was carried out to find out the optimum sowing time and to evaluate the effect of biofertilisers in combination with different sources of NP on the growth, yield, quality and productivity of groundnut.

Materials and Methods

The experiment was conducted at the Agricultural Research Station, Brinjhagiri, Chatabar, Faculty of Agricultural Sciences, Siksha 'O' Anusandhan (Deemed to be University), Bhubaneswar, Odisha, during the rabi-summer season of 2024. The experimental field had a fairly uniform topography and medium soil fertility status.

Composite surface (0–15 cm) soil samples were collected from all treatments before sowing and after harvest during the cropping period. The soil samples were analysed for chemical properties which showed that the experimental field found out had a sandy loam texture with a soil pH of 5.6, electrical conductivity (EC) of 1.45 ds m⁻¹ and organic carbon content of 0.39 %.

The experimental site is located in Khordha district, Odisha, India at 20 °N latitude and 85 °E longitude with an altitude of 58 m above mean sea level. The maximum temperature ranged from

11.5–32.2 °C was observed during the 18th and 1st standard meteorological week (SMW), respectively. The minimum temperature ranged from 14.80–28.30 °C was observed during the 1st and 17th SMW respectively. A total rainfall of 107.6 mm was recorded from January–June 2024, of which the highest monthly rainfall (80.8 mm) occurred in the month of March

The experiment was laid out in a split-plot design, where in sowing dates constituted the main plots treatments and different combinations of NP sources formed the subplot treatments. The three sowing dates were assigned to the main plots, while 6 combinations of NP sources were allocated to the subplots. The sowing dates were D₁: 2nd January 2024, D₂: 17th January 2024 and D₃: 1st February 2024, maintained at 15-day intervals. The subplot treatments comprised six combinations of NP: NP₁, full dose of N through farmyard manure (FYM) and vermicompost (V) in a 1:1 ratio along with 50 kg of P supplied through single superphosphate (SSP) and rock phosphate in a ratio 1:1; NP₂, full dose of N through FYM and VC (1:1) with the full recommended dose of P through rock phosphate; NP₃, NP₁+ seed treatment with phosphate-solubilising bacteria (PSB); NP₄, NP₁+ soil application of PSB at 7.5 kg ha⁻¹; NP₅, NP₂+ seed treatment with PSB; and NP₆, NP₂+ soil application with PSB at 7.5 kg ha⁻¹.

Groundnut variety Mallika (ICHG-00440) was used in the study. On the respective sowing dates, seeds were inoculated with rhizobium culture at 20 g/kg seed and treated with PSB according to the treatment schedule 1 hr before sowing. Sowing was carried out at a seed rate of 100 kg ha⁻¹ with a spacing of 25 cm x 10 cm on respective sowing dates. A recommended fertiliser dose of 25–50–40 kg N, phosphorus pentoxide (P₂O₅) and potassium oxide (K₂O) was applied per hectare. Single superphosphate (SSP) and rock phosphate were used as P sources for basal applications while muriate of potash (MOP) was applied as potassium (K) source. To meet the calcium (Ca) and sulfur (S) requirements of the crop, gypsum was applied at 250 kg ha⁻¹. Intercultural operations, thinning and gypsum application were carried out at 25 days after sowing (DAS), in all treatments according to the respective sowing dates. Appropriate plant protection measures were adopted whenever necessary. The crop was grown under irrigated conditions. The first irrigation was applied immediately after sowing of the seeds and subsequent irrigations were given at intervals of 10–15 days. The crop was harvested according to the respective sowing dates with D₁ harvested on 3 May 2024, D₂ on 15 May 2024 and D₃ on 27 May 2024. Pre-harvest observations included plant height (cm), number of branches per plant, dry weight per plant (g), nodules per plant and dry weight of root nodules per plant (mg). Post-harvest studies comprised number of pods per plant and kernels per pod. Kernel yield (kg ha⁻¹), haulm yield (kg ha⁻¹), protein content (%) and oil content were determined. Soil properties including texture, pH, EC, organic carbon (%) and available NP were also calculated. Protein content was estimated by multiplying the kernel nitrogen content (%) by a conversion factor of 6.25 and expressed as percentage protein content (14). Oil content in the kernel was determined by Soxhlet's apparatus using petroleum ether (60–80 °C) as the extractant (14). Oil yield (kg ha⁻¹) was calculated by multiplying kernel oil content (%) by the respective kernel yield. Phosphorus-use efficiencies, including P recovery efficiency (kg P uptake/kg P applied) and P harvest index (kg P in pods/total kg P uptake) were computed using standard formulae (15).

Results and Discussion

The data of growth parameters are presented in Table.1. The highest plant height was recorded under D₂ measuring 19.9 cm followed by D₁ (19.6cm). Among four different nutrient management treatments highest plant height was found in treatment NP₄ with plants attaining a height of 22.0 cm. The lowest plant height was recorded under D₃ at 17.8cm while the shortest plants among the nutrient management treatments were found in NP₁ measuring 16.2 cm. Similar trends were also observed in other growth parameters like number of leaves per plant, number of branches per plant and dry matter accumulation by the plants. Likewise, in D₂ the numbers of leaves per plant (44.2), branches per plant (12.3) and dry matter accumulation (18.4 g per plant) were found the maximum. Similarly in the combinations of N and P, the treatment NP₄ which received 20 kg N through FYM and VC in a 1:1 ratio along with 40 kg P through SSP and rock phosphate in a 1:1 ratio supplemented with soil application of PSB produced the highest number of leaves per plant (47.3), maximum number of branches per plant (13.5) and highest dry matter production (18.7 g/plant).

Root nodules are one of the important characteristics of groundnut. The nodulation data showed significant variation among different sowing dates and nutrient management treatments involving N and P combinations. The highest count of nodules per plant (57.2) and its dry matter (0.39 mg/plant) were recorded under D₂. Among N and P combinations, NP₄ recorded the highest number of nodules per plant (61.8) and the greatest nodule dry weight (0.432 mg per plant).

The yield attributes showed trends similar to those observed for the growth parameters, both in date of sowing and NP combinations. The highest number of pods per plant (12.3) was observed in D₂ representing a 35.78 % increase over the lowest value (9.11) which was recorded in D₃. The highest number of pods per plant (12.8) was found in NP₄, showing a 12.5 % improvement compared to the second highest (NP₆) with 11.39 pods. However, D₂ recorded highest number of kernels per pod (2.3) and the highest test weight (46.4 g). Among the NP combinations, the treatment NP₄, produced the highest number of kernels per pod (2.6) and the maximum test weight (46.6 g).

The data of pod and kernel yield are presented in Fig. 1 and Table 2. Different sowing dates and NP combinations had a significant impact on these yields. Among the sowing dates, the highest pod yield of 11.9 quintals per hectare (qha⁻¹) was recorded in D₂ which was 16.5 % higher than the 9.9 qha⁻¹ observed on D₁. Among the N and P combinations, NP₄ produced the highest pod yield of 12.2 qha⁻¹, showing a 30.35 % increase over the lowest pod yield of 8.5 qha⁻¹ recorded in NP₁. For kernel yield, D₂ again resulted the highest yield of 8.4 qha⁻¹, 22.5 % higher than the 6.5 qha⁻¹ from D₁. Second sowing date also resulted in the highest haulm yield of 28.9 qha⁻¹, which is 22.92 % greater than the haulm yield of 22.3 qha⁻¹ from D₁. Among the NP combinations, NP₄ produced the highest kernel yield of 9.2 qha⁻¹, showing an increase of 57.56 % compared to the lowest kernel yield of 3.9 qha⁻¹ from NP₁. The NP₄ also recorded the highest haulm yield of 27.8 qha⁻¹, which is 11.22 % greater than the haulm yield of 24.7 qha⁻¹ from NP₆ which ranked second among NP combinations. The highest shelling percentage was observed in D₂ (66.3 %), which was 1.37 % higher than the 65.4 % observed in D₁. Among the NP combinations, NP₄ achieved the highest shelling percentage of 67.7 %, showing 8.85 % improvement over the shelling percentage of 61.7 % from NP₁. Similar findings were reported in experiments conducted at Ratnagiri (16).

Atmospheric temperature and soil moisture directly influenced the crop production. The crop sown during the second week of January experienced favourable climatic conditions for growth and development. In contrast, delayed sowing exposed the crop to scorching heat and dry soil conditions resulted in more flower senescence. This led to decreased dry matter accumulation by individual plants which ultimately reduced the yield. When the crop was sown earlier (D₁) due to very low temperatures, the germination and initial vegetative growth hampered, thus it took more time to complete its life cycle. When the crop was sown at the proper time it received favourable climatic conditions which might be responsible for higher dry matter accumulation over early sowing (17–19).

Quality parameters

The data on quality parameters namely oil content (%), oil yield (kg ha⁻¹) and protein content (%) are presented in Table 2. The oil content, oil yield and protein content were significantly influenced

Table 1. Effect of sowing dates, nitrogen and phosphorus combinations on growth parameters and yield attributes of groundnut

Treatment	Plant height (cm)	Leaf number per plant	Branches per plant	Dry matter accumulation (g/plant)	Nodules per plant	Nodules dry weight (mg/plant)	Pods/plant	Kernels/pod	Pods weight/plant	Test weight (g)
Date of sowing										
D ₁	19.6	41.9	12.2	14.2	55.9	0.38	10.2	2.03	8.2	45.8
D ₂	19.9	44.2	12.3	18.4	57.2	0.39	12.3	2.29	9.7	46.4
D ₃	17.8	34.3	10.3	11.9	52.3	0.36	9.1	1.95	6.9	45.4
Sem ±	0.66	2.67	0.66	1.58	1.49	0.007	0.95	0.08	0.40	0.79
CD (P = 0.05)	1.84	7.42	1.82	4.38	4.13	0.018	2.64	0.22	1.12	NS
Nutrient management										
N ₁	16.2	32.4	9.7	13.1	48.5	0.34	8.3	1.76	6.0	44.9
N ₂	18.5	39.0	11.3	13.7	52.1	0.36	10.6	1.91	7.9	45.8
N ₃	19.5	41.7	12.2	14.8	56.3	0.38	11.2	2.17	8.6	45.9
N ₄	22.0	47.3	13.5	18.7	61.8	0.43	12.8	2.66	10.6	46.6
N ₅	17.6	36.7	10.1	13.5	53.9	0.37	9.0	1.78	7.0	45.6
N ₆	21.0	44.2	12.9	15.3	58.3	0.40	11.4	2.28	9.4	46.4
Sem ±	0.25	1.13	0.31	1.22	1.66	0.006	0.39	0.07	0.36	0.50
CD (P = 0.05)	0.72	2.30	0.64	2.50	3.39	0.013	0.79	0.157	0.73	NS
Interaction D x NP										
Sem ±	1.48	5.98	0.22	3.53	2.78	0.01	10.24	0.17	0.90	1.76
CD (P = 0.05)	S	S	S	S	NS	NS	12.32	S	S	NS
Interaction NP x D										
Sem ±	0.61	1.95	0.07	2.12	1.79	0.01	0.95	0.12	0.62	0.86
CD (P = 0.05)	S	S	S	S	NS	NS	S	S	S	NS

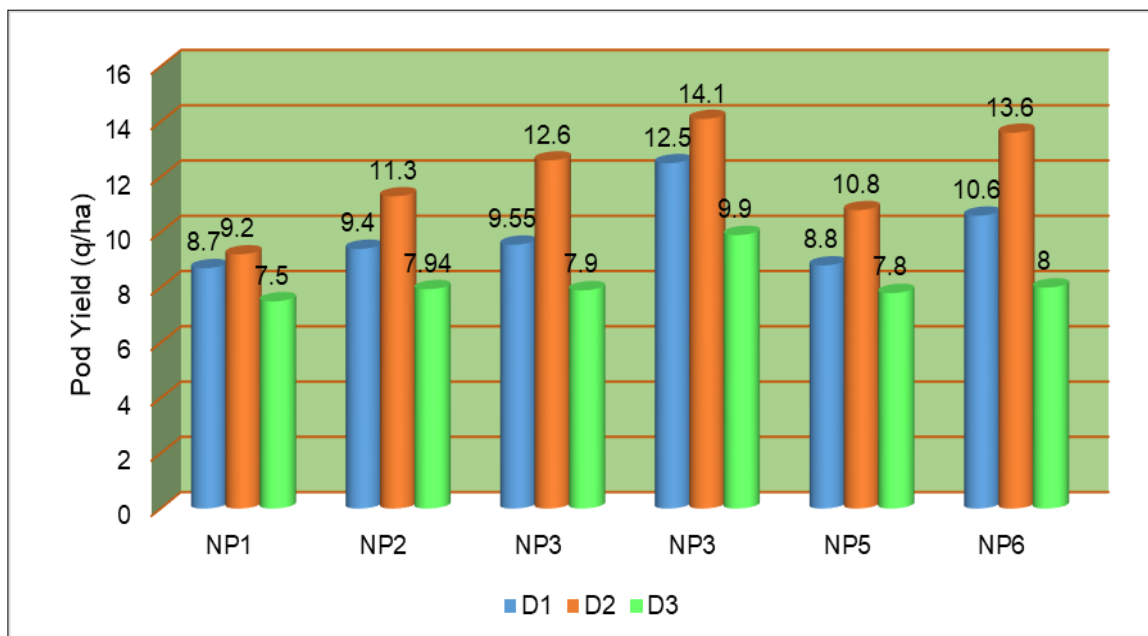


Fig. 1. Pod yield of groundnut.

Table 2. Effect of sowing of nitrogen phosphorus management on yields

Treatment	Pods yield (q ha ⁻¹)	Kernel yield (q ha ⁻¹)	Haulm yield (q ha ⁻¹)	Oil content (%)	Shelling percentage (%)	Oil yield (kg ha ⁻¹)	Protein content (%)	P uptake by kernel (kg ha ⁻¹)	P uptake by haulm (kg ha ⁻¹)
Date of sowing									
D ₁	9.9	6.5	22.3	49.4	65.4	466.6	18.7	3.7	1.8
D ₂	11.9	8.4	28.9	49.8	66.3	595.4	20.3	4.5	2.2
D ₃	8.2	4.3	18.5	47.1	62.3	405.8	14.9	2.9	1.4
Sem ±	0.51	0.89	1.19	0.59	1.21	23.76	1.27	0.097	0.098
CD (P = 0.05)	1.38	2.47	3.31	1.64	3.35	65.96	3.53	0.270	0.271
Nutrient management									
N ₁	8.5	3.9	18.2	45.9	61.7	412.1	11.6	2.5	1.4
N ₂	9.5	6.2	21.5	48.4	63.1	468.0	17.7	3.6	1.7
N ₃	10.0	6.9	23.3	49.3	65.9	481.4	19.2	3.8	1.8
N ₄	12.2	9.2	27.8	51.6	67.7	592.4	22.6	5.00	2.4
N ₅	9.2	4.9	20.6	47.1	62.8	450.5	15.7	3.3	1.5
N ₆	10.7	7.5	24.7	50.4	66.7	531.1	20.9	4.2	2.1
Sem ±	0.65	0.57	1.21	0.19	0.66	31.96	1.15	0.118	0.118
CD (P = 0.05)	1.34	1.16	2.47	0.39	1.36	65.27	2.23	0.242	0.241
Interaction D x NP									
Sem ±	1.13	1.99	1.66	1.32	2.70	34.06	2.67	0.217	0.201
CD (P = 0.05)	S	S	S	S	S	S	S	S	S
Interaction NP x D									
Sem ±	0.92	0.98	1.19	0.33	1.15	18.97	1.51	0.205	0.198
CD (P = 0.05)	S	S	S	S	S	S	S	S	S

by the sowing date. The D₂ recorded highest oil content (49.8 %), which was 5.42 % higher than D₃. Similarly, the highest oil yield (595.4 kg ha⁻¹) and protein content (20.3 %) were obtained in D₂ and which was followed by D₁ producing an oil yield of 466.6 kg oil ha⁻¹ and protein content of 7.5 % representing reductions of 21.61% and 18.7 % respectively, compared with D₂. In N and P combinations when the NP₄ treatment which received 20 kg N through FYM and VC in a 1:1 ratio along with 40 kg P through SSP and rock phosphate in a 1:1 ratio supplemented with soil application of PSB, produced the highest oil content (51.6 %), oil yield (592.4 kg ha⁻¹) and protein content (22.6%).

Overall, the crop received Ca and S from gypsum. In addition, different nutrient management treatment combinations supplied supplementary S and the application of PSB enhanced P availability in the soil.

Phosphorus uptake and phosphorus use efficiency

Phosphorus uptake by kernel and haulm

The highest P uptake by the kernel was found on D₂ recording 4.5 kg

ha⁻¹. The lowest P uptake (2.9 kg ha⁻¹) by the kernel was found on D₃. A similar trend was also found in haulm where the highest (2.2 kg ha⁻¹) uptake was recorded on D₂.

Among the nutrient management treatments NP₄ recorded the highest P uptake by the kernel with a value of 5.0 kg ha⁻¹. It was at par with the treatment NP₆ which showed a kernel P uptake of 4.2 kg ha⁻¹. The highest phosphorus uptake by haulm was observed in NP₄ counting 2.4 kg ha⁻¹. The lowest P uptake by both kernel and haulm was recorded in the treatment of NP₁ with values of 2.5 kg ha⁻¹ and 1.4 kg ha⁻¹ respectively. The increased P uptake may be attributed to the higher P content in pod and haulm resulting from the integrated application of different P sources. It may also be due to the enhanced dissolution and availability of P from SSP mixture, in the presence of FYM and PSB, which may have increased P absorption by the crop and ultimately resulted in higher pod yield (3,20).

Phosphorus (P)-use efficiency

The computed P-use efficiency indices are presented in Fig. 2. The highest P recovery efficiency and P harvest index were found under

D₂. Among NP combinations, the treatment received 25 kg N through FYM and VC in a 1:1 ratio along with 50 kg P₂O₅ through SSP and RP in a 1:1 ratio and soil application of PSB at 7.5 kg ha⁻¹, recorded the highest values of P recovery efficiency and P harvest index of 5.51 and 15.83 respectively. These results are consistent with previous studies demonstrating the role of PSB in enhancing P solubility, mobility, release availability in the soil (3). It has been reported that PSB and PSM, play an important role in the release of different organic acids such as citric, oxalic, gluconic succinic, α -ketoglutaric and fumaric acid which are responsible for transforming insoluble forms of P into soluble ones (21).

Economics

The cost of cultivation varied among treatments due to the differences in input costs, such as manure, biofertilisers and fertilisers. The net return and the return per rupee invested were found to be the highest (₹36219 and ₹1.67) in the treatment combination D₂NP₄ (Fig. 3). When the crop was sown late it has been observed that except in D₃NP₄ and D₃NP₆, all other late-sown treatments recorded negative net returns. This may be due to the scorching sunlight and high temperature during the late sown

conditions, which may have reduced crop yield and consequently resulted in negative returns. Similar findings were also reported from, Odisha conditions (12). Early sowing during the third standard meteorological week (SMW) was found to be optimum for achieving maximum pod yield of groundnut compared with the other sowing windows in this region of Odisha. The use of RP and SSP in equal proportions and FYM and VC in equal proportions as a source of P and N respectively along with soil application of PSB (7.5 kg ha⁻¹) produced the highest pod and oil yields. This treatment also found to be the best in terms of P-use efficiency and P recovery efficiency when the crop was sown during third SMW.

Correlation studies

The correlation between the mean temperature during the crop growth period and kernel yield across different sowing dates is presented in Fig. 4. Kernel yield under different dates of sowing was directly influenced by the average temperature of that period. The study clearly showed a positive significant correlation ($R^2 = 0.58$) between pod yield and average temperature. The result revealed higher pod yield under a favourable mean temperature of approximately 28 °C whereas temperatures beyond 30 °C relatively

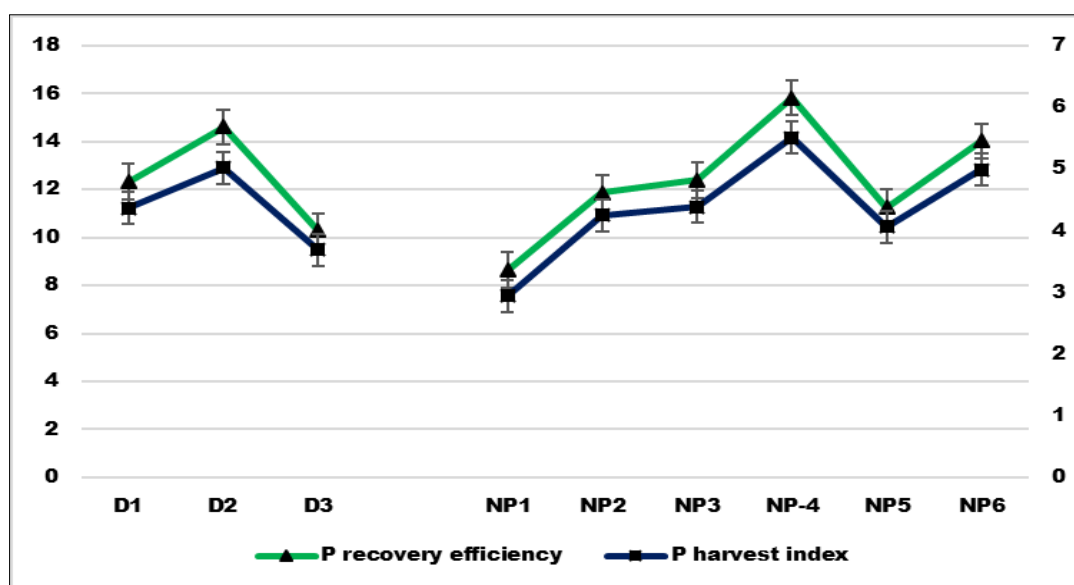


Fig. 2. P recovery efficiency and P harvest index of ground under different sowing dates and nitrogen and phosphorus combinations.

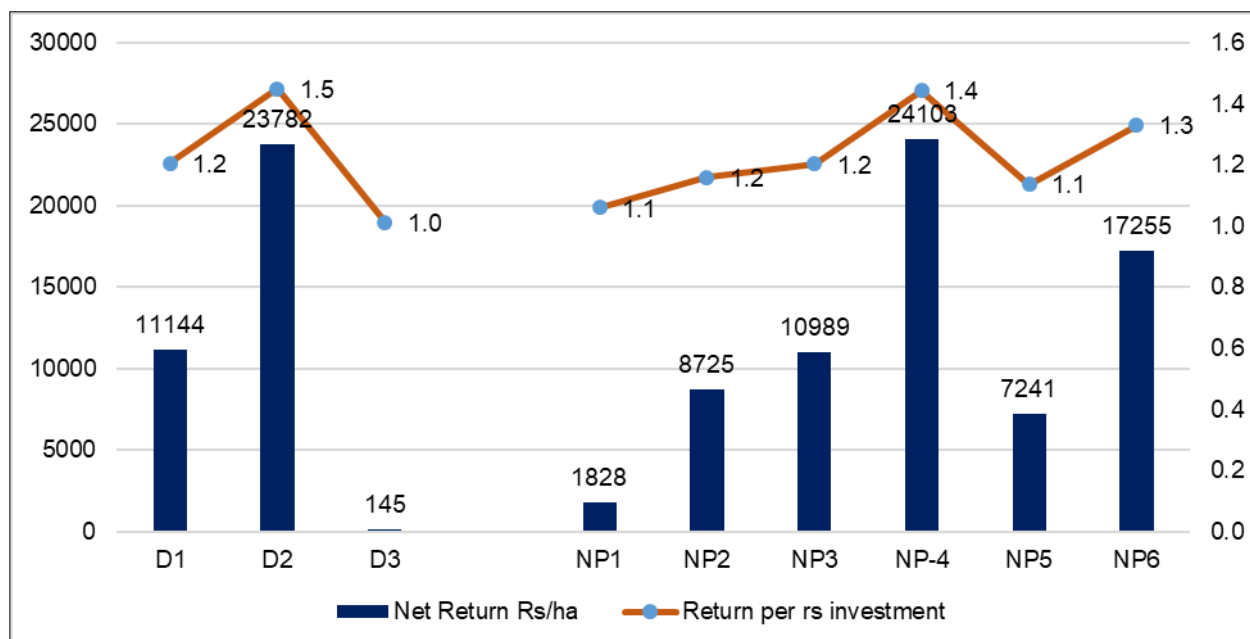


Fig. 3. Net rerun and return per rupee invested.

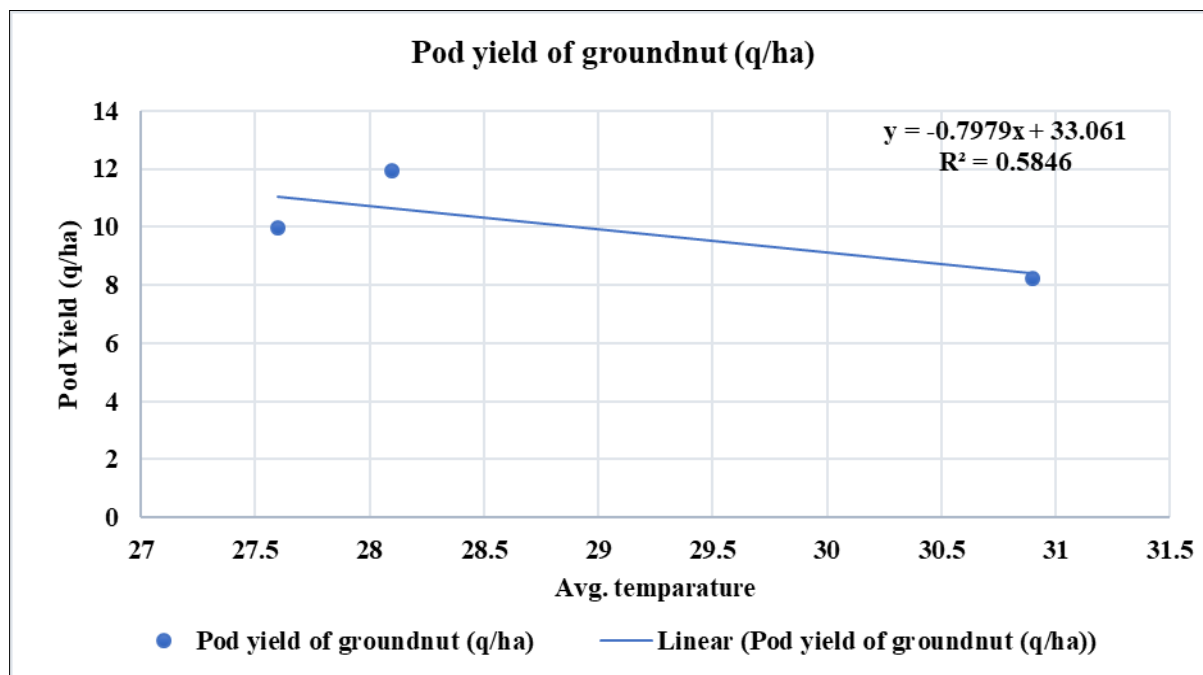


Fig. 4. Correlation between pod yield and mean temperature.

decreased the yield. This may be due to sharp rise in temperature during the later stages of crop growth, particularly in April and May which created an unfavourable condition in the anthesis resulting in poor pod formation and low yield. When the crop was sown in early January, the minimum temperature remained low which led to slow vegetative growth which also reduced the crop yield.

The relationship between the nodules per plant and total P uptake showed a strong positive correlation ($R^2 = 0.98$) (Fig. 5). Total phosphorus uptake improved the number of nodules, indicating enhanced nutrient acquisition. Furthermore, the relationship between nodules per plant and kernel yield of groundnut also showed a positive correlation ($R^2 = 0.39$) (Fig. 6). These findings clearly show that the treatment having increased nodulation improves P utilisation efficiency, thereby contributing to higher kernel yield.

Conclusion

Groundnut sown during the third standard meteorological week (SMW), corresponding to 17 January (D_2), was found to be the optimum sowing time under the agroclimatic conditions of Odisha as it recorded the highest pod (11.9 q ha^{-1}) and kernel yield (8.4 q ha^{-1}). This treatment also produced the highest oil content and protein content, indicating superior quality attributes. Consequently, it also generated the highest net return and benefit-cost ratio. Among the nutrient management treatments the application of farmyard manure (FYM) and vermicompost (VC) in a 1:1 ratio as nitrogen sources together with single superphosphate (SSP) and rock phosphate (RP) in a 1:1 ratio as phosphorus sources, supplemented with soil application of phosphate-solubilising bacteria (PSB) at 7.5 kg ha^{-1} produced the highest pod and kernel yields, oil content and protein content. This treatment also exhibited the highest phosphorus-use efficiency and phosphorus recovery efficiency. The higher yield and better-quality products help this

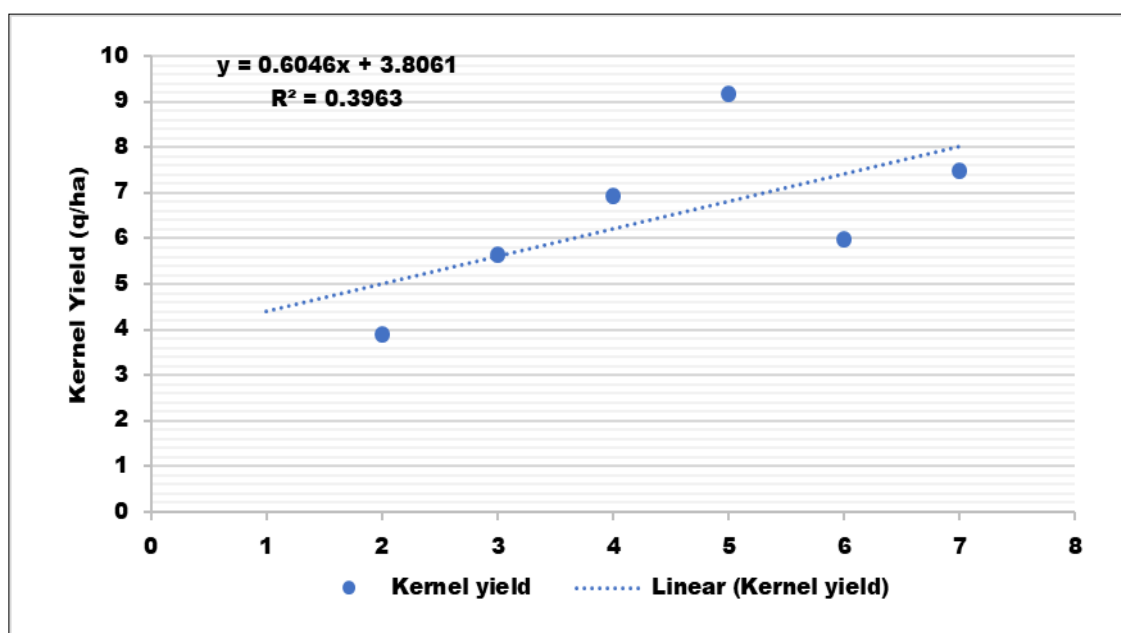


Fig. 5. Correlation between nodules per plant and kernel yield.

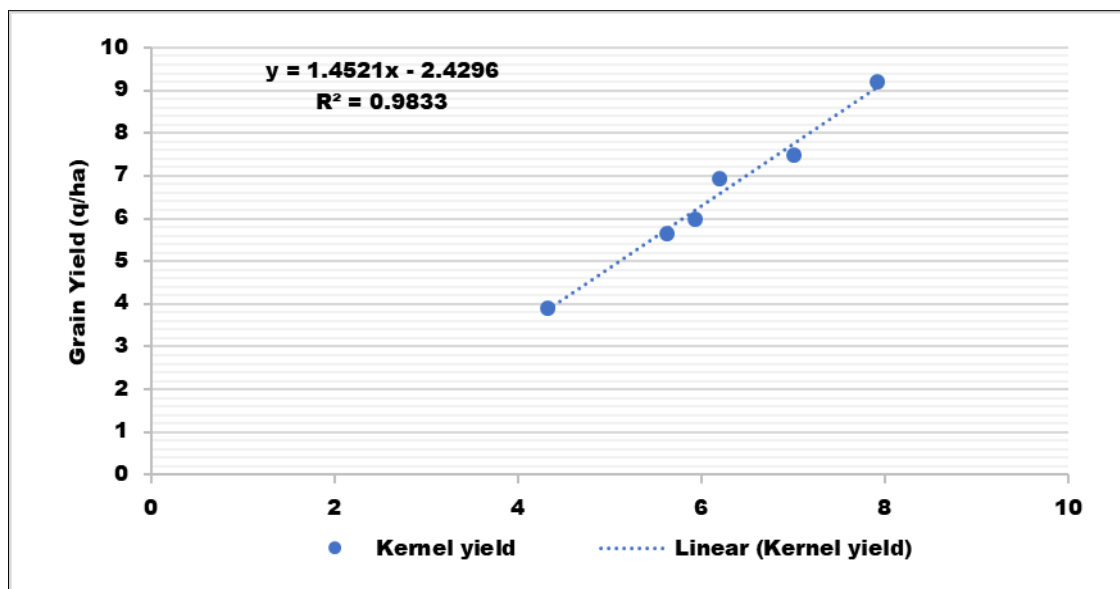


Fig. 6. Correlation between phosphorus total uptake and kernel yield.

treatment to get highest monetary returns and the different nutrient management practices. Therefore, it can be summarised that sowing of groundnut during third SMW (17th January) in combination with integrated nutrient management involving FYM, VC, SSP, RP and PSB can be considered best for achieving higher yield, best quality and maximum economic returns under the agroclimatic conditions of Odisha. Adopting these treatments may also contribute to improved soil health and enhanced microbial activity in the soil.

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Authors' contributions

SS¹ carried out the field experiments, laboratory work and took the lead in drafting and preparing the manuscript. SS² contributed to data interpretation and manuscript revision. RM and SS² performed the statistical and sequence analysis and also assisted in interpreting the results. MRC and KS provided overall guidance and critically reviewed the manuscript for important intellectual content. All the authors read and approved the final manuscript [SS¹ stands for Subhashree Sarangi and SS² stands for Subhadarsi Samantasinghar].

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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