



RESEARCH ARTICLE

Effect of gypsum levels and application timing for improved growth, yield and oil productivity of groundnut (*Arachis hypogaea* L.) in Southern Odisha

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Abstract

During the rabi season (2023–2024), a field experiment was conducted at the Post-Graduate Research Farm, M.S. Swaminathan School of Agriculture, Centurion University of Technology and Management, Odisha, to evaluate the effect of gypsum levels and time of application on the growth, yield and oil productivity of groundnut. The experiment was laid out in a factorial randomised block design (FRBD) with three replications. The treatments comprised three gypsum rates (100, 200 and 300 kg/ha) and four application timings (basal, pegging, pod-formation and split application: 50 % at pegging + 50 % at pod formation). Growth parameters, pod yield, kernel yield, haulm yield, biological yield, kernel oil (%), oil yield and plant calcium and sulphur concentrations/uptake were recorded. Gypsum application at 300 kg/ha significantly improved plant height, number of branches per plant and dry matter by 6.8 %, 20.1 % and 9.4 % respectively, over 100 kg/ha. Kernel and pod yields increased by 13.4 % and 8.9 %, while oil content and oil yield increased by 8.2 % and 19.3 % respectively. Basal application (at sowing) outperformed late application (at pod formation), with increases of up to 16.2 % in plant height, 77.8 % in branches, 28.5 % in dry matter, 39.9 % in kernel yield and 49.8% in oil yield. Basal application recorded the highest kernel oil content (46.9 %) and oil yield (975 kg/ha). The findings demonstrate that gypsum at 300 kg/ha, applied at sowing, is best for enhancing the growth and productivity of groundnut.

Keywords: calcium; gypsum; nutrient management; peanut; productivity; sulphur

Introduction

Groundnut (*Arachis hypogaea* L.) is a major oilseed crop that plays an important role in global agriculture (1). China and India are the two leading producers, underlining the crop's strong nutritional and economic importance in the region. Owing to its adaptability, groundnut is cultivated and traded worldwide across diverse environments (2). It contributes significantly to global food security and agricultural economies, being grown from tropical to temperate zones and serving as a vital source of food and income for millions. Globally, groundnuts occupy about 32.7 million hectares, producing 53.9 million tones annually in 2021 (3). Groundnut kernels contain 40–50 % oil, 25–46 % protein and 10–15 % carbohydrates, along with 55.5 % of vitamin E, 54 % of phosphorus and 10–53 % of vitamins B and 42 % magnesium, 127 % copper, 84 % manganese and 57 % iron (4, 5). Groundnut oil accounts for approximately 7–10 % of all vegetable oils extracted and 75–80 % of the groundnuts produced in India are crushed for oil, which is widely used in households and industries (5).

Optimal crop nutrition is critical to achieve high productivity (6). Groundnut, also known as peanut, earthnut and monkey nut, is commonly referred to as the “king of oilseeds.” The crop removes substantial amounts of macro and micronutrients from the soil, thereby requiring balanced nutrient management for

sustainable productivity. The crop also performs better in rainfed and drought conditions due to its ability to absorb nutrients from deeper soil layers (8).

Soil amendments such as gypsum provide calcium and sulphur, which improve soil physico-chemical properties, enhancing structure, water-holding capacity, nutrient availability and microbial activity, thereby creating a favourable environment for root development and plant growth (9). Being more soluble than lime, gypsum enhances calcium mobility in soil and is available to plants, improves soil aggregation, reduces crusting and increases water infiltration in heavy soils (10). Sulphur also plays a key role in oil and amino acid synthesis, improving both yield and quality (11). While the importance of gypsum is well established, the timing of its application is equally critical. Calcium and sulphur added through gypsum provide a positive response in yield by enhancing growth at different developmental stages, including peg formation and pod development (12). Basal application supplies nutrients at sowing for early growth, which in turn enhances growth at pegging for peg penetration and at pod formation for seed filling (13). Since gypsum-derived calcium is more mobile than lime, synchronising gypsum application with these growth stages may substantially improve peg set, pod filling, kernel yield and oil productivity (9, 13).

Under these circumstances and considering the intensive cultivation practices in the region that led to repeated depletion of primary and secondary nutrients, the present study was undertaken to determine the optimal rate and timing of gypsum application for maximising groundnut growth, yield and oil productivity under Southern Odisha conditions.

Materials and Methods

The field experiment was conducted during the rabi season of 2023–24 at the Post-Graduate Research Farm, M.S. Swaminathan School of Agriculture (MSSSoA), Centurion University of Technology and Management (CUTM), Paralakhemundi, Odisha, India, to evaluate the effect of different levels and timings of gypsum application on the growth and yield of groundnut under Southern Odisha conditions. The experimental soil was sandy loam. The initial soil status of the field under Southern Odisha conditions is presented in Table 1. The experiment was conducted from November 22, 2023, to March 29, 2024. The meteorological parameters during the study period, including rainfall, maximum and minimum temperatures, sunshine hours and relative humidity, are depicted in Fig. 1 & 2.

The experiment was laid out in a factorial randomised block design (FRBD) with two factors and three replications, comprising 12 treatment combinations. Factor A included three gypsum levels: A1 = 100 kg/ha, A2 = 200 kg/ha and A3 = 300 kg/ha. Factor B comprised four application timings: B1 = basal application, B2 = pegging stage, B3 = pod formation stage and

B4 = split application (50 % at pegging + 50 % at pod formation). The net plot size was 4.5 m × 3.6 m. The groundnut variety TCGS 1694 (Tirupati), an early-maturing variety suitable for both rabi and kharif seasons and tolerant to drought, was sown at a spacing of 30 cm × 10 cm (14). The gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) product used contained 23.3 % calcium and 18.6 % sulphur. Land preparation included ploughing with a tractor-drawn cultivator, followed by a rotavation to obtain a fine tilth conducive to germination and peg formation. The recommended basal dose of nitrogen, phosphorus and potassium (20:40:40 kg/ha) was applied through urea, single superphosphate and muriate of potash respectively (11). Gypsum was applied according to the treatment schedule. Observations recorded included growth parameters, days to 50 % flowering, days to peg initiation, yield attributes, yield, quality traits (oil content and oil yield), nutrient content (%), nutrient uptake (kg/ha) and soil nutrient status (kg/ha).

Statistical analysis

Data were analysed using analysis of variance (ANOVA) in MS Excel and treatment means were compared using the critical difference (CD) at the 5 % level of significance (15). Correlation analyses of nutrient uptake and yield parameters performed using R software (version 4.4.2) in RStudio on Windows.

Results and Discussion

Effect of different levels and timings of gypsum application on growth parameters of groundnut

The plant height, number of branches per plant, dry matter accumulation, days to 50 % flowering and days to peg initiation were significantly influenced by different levels and times of gypsum application (Table 2).

Plant height

Among the different gypsum levels, the application of 300 kg/ha (A3) recorded the highest plant height (45.7 cm), which was statistically at par with 200 kg/ha (A2: 44.0 cm). The superior performance at higher gypsum levels can be attributed to the adequate supply of calcium and sulphur, which enhance cell division, cell elongation and overall vegetative growth (10, 11). The comparable performance of A2 with A3 indicates that the calcium and sulphur requirements for optimum plant growth may be largely met at 200 kg/ha, beyond which further increases have a marginal effect.

Table 1. Initial soil characteristics of the field under Southern Odisha conditions

Sl. No.	Properties	Value
A	Physical properties	
1	Sand (%)	58.1
2	Silt (%)	26.3
3	Clay (%)	15.5
4	Textural class	Sandy loam
B	Chemical properties	
1	pH	6.3
2	Electrical conductivity (ds/m)	0.5
3	Organic carbon (%)	0.3
4	Available nitrogen (kg/ha)	226
5	Available phosphorus (kg/ha)	15
6	Available potassium (kg/ha)	126
7	Available calcium (cmolc/kg)	0.87
8	Available sulphur (mg/kg)	8.79

Table 2. Effect of gypsum application rate and timing on growth parameters of rabi groundnut

Treatments	Plant height (cm)	Number of branches/plant	Dry matter Accumulation (g/m ²)	Days to 50 % flowering	Days to peg initiation
Levels of gypsum (A)					
A1-100 kg/ha	42.8	9.3	512	34.4	44.3
A2-200 kg/ha	44.0	10.3	558	32.7	42.7
A3-300 kg/ha	45.7	11.2	560	32.7	43.1
S.Em. ±	0.7	0.4	13.4	1.0	1.0
CD (P = 0.05)	2.2	1.2	39.3	NS	NS
Time of application of gypsum (B)					
B1-Basal	47.3	12.7	604	30.6	40.6
B2-At pegging stage	45.4	11.6	558	33.2	43.6
B3-At pod formation stage	40.7	7.1	470	35.2	45.2
B4-Split application	43.3	9.6	541	34.1	44.0
S.Em. ±	0.9	0.5	15.5	1.2	1.2
CD (P = 0.05)	2.5	1.4	45.3	NS	NS
Interaction (A×B)					
S.Em. ±	1.5	0.8	26.8	2.0	2.1
CD (P = 0.05)	NS	NS	NS	NS	NS

Note: S.Em. = standard error of mean; CD = critical difference; NS = non-significant.

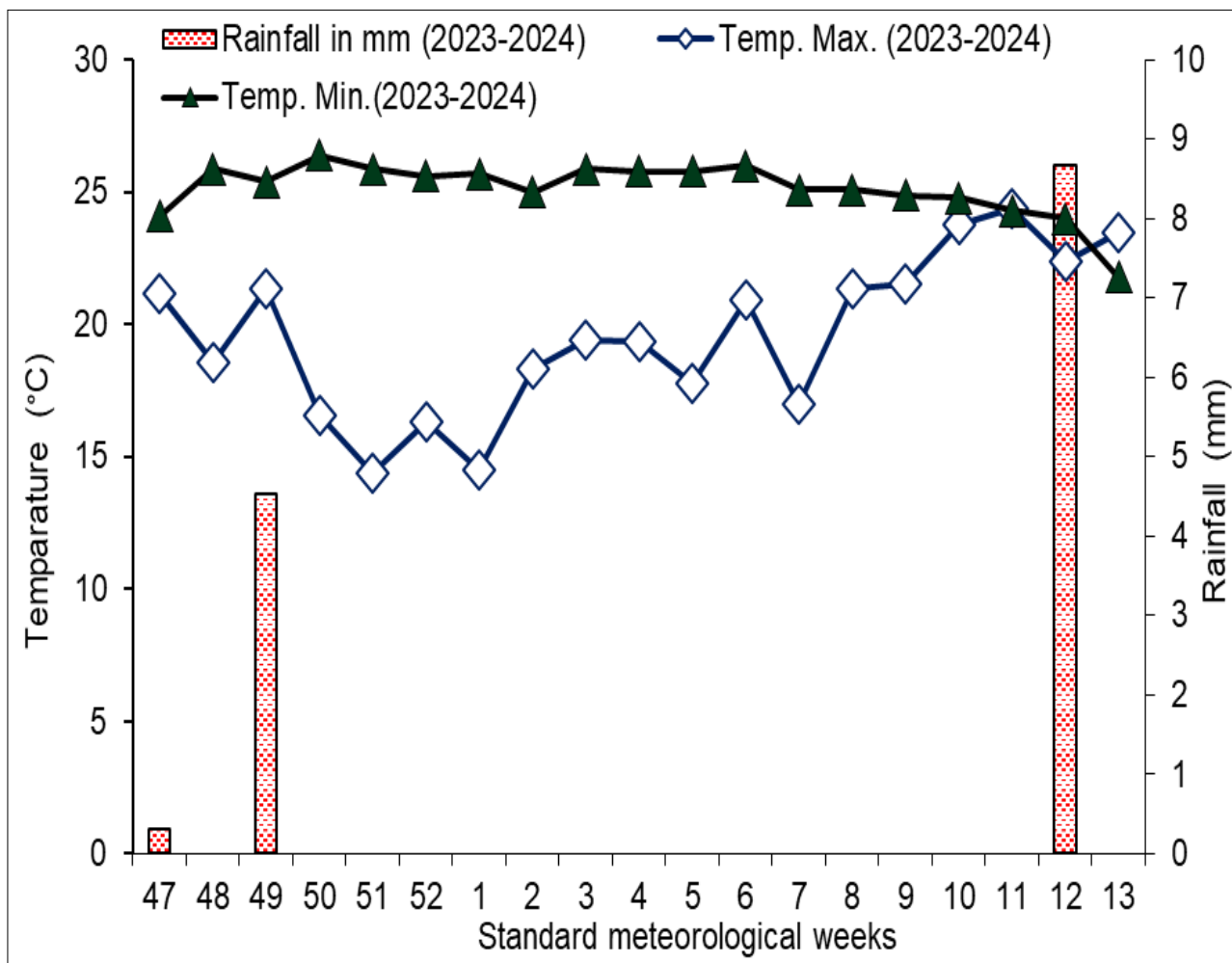


Fig. 1. Rainfall and temperature (maximum and minimum) conditions during the study period.

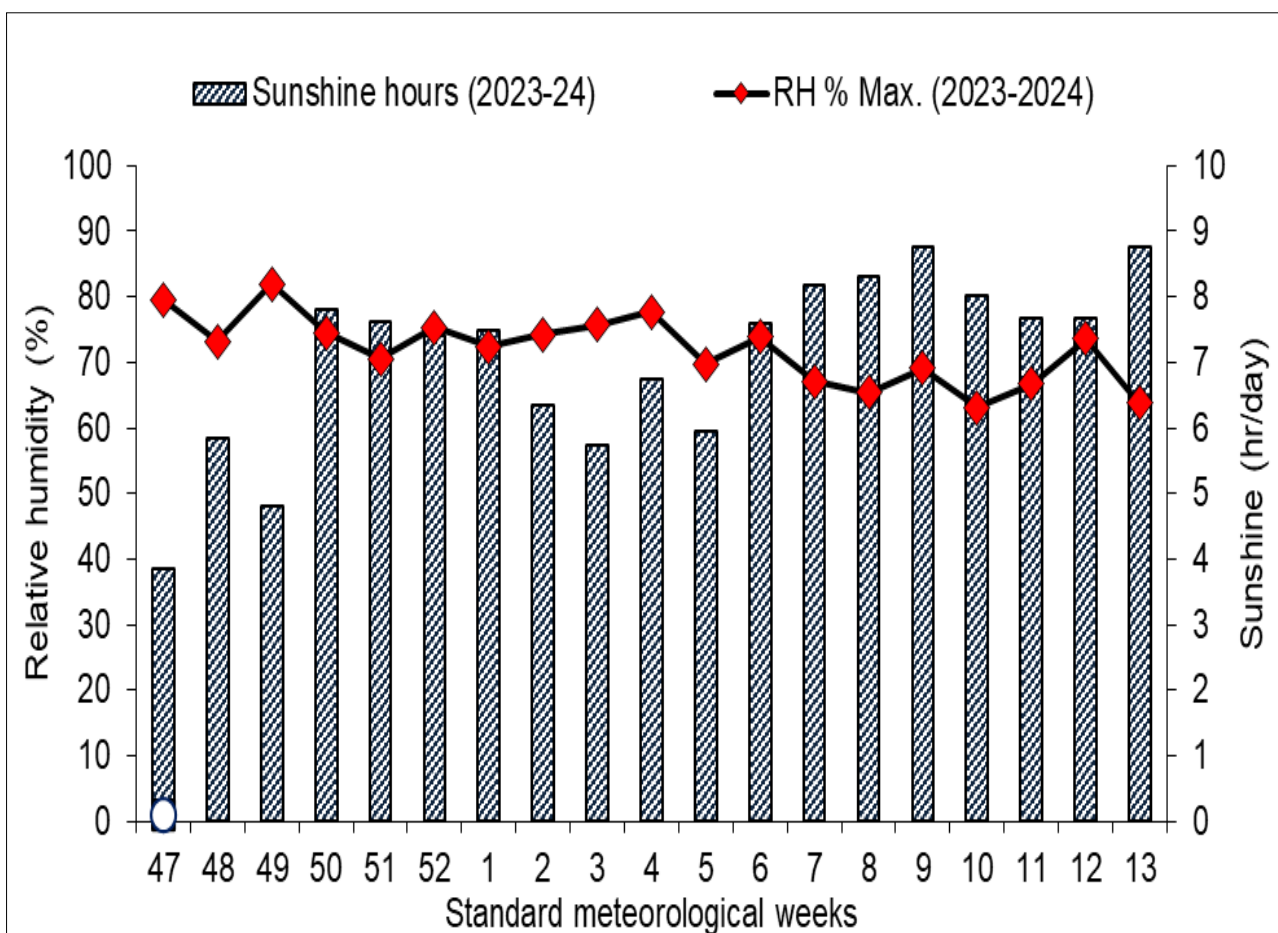


Fig. 2. Sunshine duration and relative humidity conditions during the period of study.

Regarding the timing of gypsum application, basal application at sowing (B1) produced the highest plant height (47.3 cm), closely followed by application at the pegging stage (45.4 cm), with both treatments being statistically at par. The superiority of basal application may be attributed to the early and continuous availability of calcium and sulphur, which supports initial growth, root establishment and nutrient uptake (11). In contrast, application at the pegging stage ensures nutrient availability during the reproductive transition, supporting stem elongation comparable to basal application (12).

Number of branches per plant

Among the gypsum levels, application of 300 kg/ha produced the maximum number of branches per plant (11.2), followed by 200 kg/ha (10.3). The increase in branching at higher gypsum levels may be attributed to an adequate supply of calcium and sulphur, which promote cell division, nutrient uptake and photosynthetic efficiency, thereby enhancing vegetative growth and lateral bud development (11). Regarding the timing of gypsum application, basal application at sowing produced the highest number of branches (12.7), followed by application at the pegging stage, while the minimum (7.1) was recorded in the pod formation stage application. The superiority of basal application can be ascribed to the early availability of calcium, which strengthens the structural framework of the plant and sulphur, which enhances protein synthesis and energy metabolism during the critical vegetative growth phase (11, 12).

Dry matter accumulation

Among the gypsum levels, application of 300 kg/ha resulted in the highest dry matter accumulation (560 g/m²), which was statistically at par with that recorded at 200 kg/ha (558 g/m²). Improved dry matter accumulation at higher gypsum levels was associated with adequate calcium and sulphur supply, which enhanced nutrient absorption, nutrient assimilation and metabolic functions, thereby supporting greater biomass production (17). With respect to timing, basal application at sowing produced the maximum dry matter accumulation (604 g/m²), statistically at par with application at the pegging stage (558 g/m²). Similarly, higher values under basal application were attributed to early and sustained availability of calcium and sulphur, which promoted growth, root proliferation and efficient nutrient uptake (11, 17).

Days to 50 % flowering and days to peg initiation

Neither days to 50 % flowering nor peg initiation in groundnut were significantly influenced by the levels and timings of gypsum application, nor by their interaction. Higher gypsum levels (200 and 300 kg/ha) and basal application tended to result in earlier flowering, despite numerical variations; lower gypsum levels (100 kg/ha) and application at pod formation slightly delayed both stages. Likewise, peg initiation was delayed with 100 kg/ha gypsum and its application at pod formation, whereas fewer days to peg initiation were recorded with 200 kg/ha gypsum applied basally. These non-significant results indicate that crop phenology was not influenced by gypsum application under the experimental conditions, irrespective of dose or timing. The slight delay in flowering and peg initiation in A1 may be attributed to comparatively slower vegetative growth and nutrient assimilation, which can extend the duration required for floral initiation (18).

The interaction effect between gypsum levels and application timings was non-significant for plant height, number of branches, dry matter accumulation, peg initiation and 50 % flowering in groundnut. This indicates that the effects of these two factors were independent and the observed responses could be attributed to either higher gypsum levels or timely application without any synergistic interaction between them.

Effect of different levels and timings of gypsum application on the yield of groundnut

Pod yield, kernel yield, haulm yield and biological yield were significantly influenced by the different levels and timings of gypsum application, whereas the interaction effect between these factors was non-significant. The non-significant interaction indicates that the beneficial effects of higher gypsum levels and basal application were independent, without any synergistic improvement when combined (11) (Table 3).

Pod yield (q/ha)

Among the different gypsum levels, application of 300 kg/ha recorded the highest pod yield (25.2 q/ha), which was statistically at par with gypsum at 200 kg/ha (24.7 q/ha). The increase in yield with higher gypsum levels may be attributed to improved peg initiation, better pod filling and enhanced kernel development resulting from an adequate and continuous supply of calcium and sulphur during reproductive growth (18). With regard to the timing of gypsum application, basal application at sowing recorded a

Table 3. Effect of different levels and timing of gypsum application on the yield, shelling percentage and harvest index of rabi groundnut

Treatments	Pod yield (q/ha)	Kernel yield (q/ha)	Haulm yield (q/ha)	Biological yield (q/ha)	Shelling percentage (%)	Harvest index (%)
Levels of gypsum (A)						
A1-100 kg/ha	23.1	17.2	35.9	59.4	73.7	38.1
A2-200 kg/ha	24.7	18.6	37.7	62.4	75.2	39.4
A3-300 kg/ha	25.2	19.5	38.1	63.7	77.1	39.6
S.Em. ±	0.3	0.4	0.5	0.6	1.8	0.4
CD (P = 0.05)	0.9	1.0	1.5	1.8	NS	1.3
Time of application of gypsum (B)						
B1-Basal	26.9	21.0	39.8	67.1	78.0	40.0
B2-At pegging stage	25.1	19.2	38.7	63.8	76.6	39.2
B3-At pod formation stage	21.4	15.0	33.0	55.0	69.8	37.9
B4-Split application	23.9	18.4	37.3	61.3	76.9	39.1
S.Em. ±	0.4	0.4	0.6	0.7	2.1	0.5
CD (P = 0.05)	1.0	1.2	1.7	21.3	6.1	1.4
Interaction (A×B)						
S.Em. ±	0.6	0.7	1.0	1.3	3.6	0.9
CD (P = 0.05)	NS	NS	NS	NS	NS	NS

Note: S.Em. = standard error of mean; CD = critical difference; NS = non-significant.

significantly higher pod yield (26.9 q/ha) than all other treatments. The early application of gypsum likely ensured a continuous supply of calcium in the pegging zone, thereby promoting higher peg survival, effective pod setting and improved translocation of assimilates to developing pods (11, 16, 17).

Kernel yield (q/ha)

Among the gypsum levels, application of 300 kg/ha recorded the highest kernel yield (19.5 q/ha), which was statistically at par with 200 kg/ha gypsum application (18.6 q/ha). The lowest kernel yield was recorded with gypsum application at (17.2 q/ha). The improvement in kernel yield with higher gypsum levels can be attributed to increased pod number, higher pod weight and better seed filling due to the adequate availability of calcium and sulphur during the reproductive period (18). Higher doses of gypsum increase nutrient availability in soil, helping crops to absorb and utilise calcium and sulphur at important growth phases (12). With respect to the timing of gypsum application, basal application at sowing produced the maximum kernel yield (21.0 q/ha), which was significantly superior to all other treatments. This may be due to the early application of gypsum in the pegging zone, which improves carbohydrate metabolism, enzyme activation and efficient translocation of assimilates to seeds (16, 18, 19).

Haulm yield (q/ha)

Among the different gypsum levels, application of 300 kg/ha recorded the highest haulm yield (38.1 q/ha), which was statistically at par with gypsum at 200 kg/ha (37.7 q/ha). The lowest haulm yield was observed with gypsum at 100 kg/ha (35.9 q/ha). The increase in haulm yield at higher gypsum levels may be due to improved crop growth parameters and better photosynthetic activity, resulting from enhanced calcium and sulphur nutrition (16). Higher yield associated with gypsum application is primarily attributed to increased plant biomass and height, resulting from enhanced nutrient uptake and improved photosynthetic efficiency at different growth stages (12).

With respect to the timings of gypsum application, basal application at sowing produced the maximum haulm yield (39.8 q/ha), which was statistically at par with application at the pegging stage (38.7 q/ha). The higher haulm yield under basal application could be attributed to the early availability of nutrients, leading to vigorous vegetative growth and prolonged photosynthetic activity (11, 16).

Biological yield (q/ha)

Application of 300 kg/ha gypsum recorded the highest biological yield (63.7 q/ha), which was statistically at par with 200 kg/ha (62.4 q/ha), while the lowest yield was obtained with 100 kg/ha (59.4 q/ha). With respect to timing, basal application at sowing produced the maximum biological yield (67.1 q/ha), which was significantly superior to all other treatments (18). This may be attributed to improved plant growth, a better-developed root system and enhanced nutrient uptake, ultimately contributing to yield attributes (11, 19).

Shelling percentage (%)

Among the different gypsum levels, application of 300 kg/ha recorded the highest shelling percentage (77.4 %), followed by gypsum application at 200 kg/ha (75.2 %). The lowest shelling percentage was observed with gypsum at 100 kg/ha (73.7 %). The

improvement in shelling percentage at higher gypsum levels may be attributed to better seed filling and maturity due to adequate calcium and sulphur availability (19, 20). With respect to the timing of gypsum application, basal application at sowing produced the maximum shelling percentage (78.0 %), which was at par with gypsum application at pegging stage (76.6 %) and split application (76.9 %). This may be due to the early availability of nutrients such as calcium and sulphur from gypsum, leading to improved growth, yield attributes and shelling percentage (17).

Harvest index (%)

Among the different gypsum levels, application of 300 kg/ha recorded the highest harvest index (39.6 %), which was statistically comparable to gypsum at 200 kg/ha (A2: 39.4 %). The lowest harvest index was observed with 100 kg/ha (38.1 %). The improvement in harvest index at higher gypsum levels could be due to a proportionately greater increase in physiological and biochemical processes, which positively enhanced growth and development (16).

Regarding the time of application, basal application at sowing recorded the maximum harvest index (40.0 %) and was statistically at par with application at the pegging stage (39.2 %) and split application (39.1 %). This indicates that, although basal application was superior, later applications also maintained comparable efficiency in partitioning biomass towards pods (13).

Effect of different levels and timings of gypsum application on quality parameters of groundnut

Oil content and oil yield in kernels were significantly influenced by different levels and timings of gypsum application, whereas the interaction effect between the two factors was non-significant. This indicates that the effect of gypsum rate on oil yield was independent of the application timing (Table 4).

Oil content (%)

The highest oil content (46.2 %) was recorded with the application of 300 kg/ha, which did not differ significantly from gypsum at 200 kg/ha (45.4 %). The lowest oil content was obtained with gypsum at 100 kg/ha (42.7 %). The increase in oil content at higher gypsum levels may be attributed to better sulphur availability, which promotes efficient seed development and oil biosynthesis (17–19). Regarding the timing of gypsum application, basal application at sowing resulted in the maximum oil content (46.9 %), which was not significantly different from application at the pegging stage (46.6 %). Similar findings of higher oil content with basal application have been reported in previous studies (21).

Oil yield (kg/ha)

The highest oil yield (901 kg/ha) was recorded with the application of 300 kg/ha of gypsum, followed by 200 kg/ha (846 kg/ha), while the lowest yield (755 kg/ha) was obtained with 100 kg/ha. The increase in oil yield at higher gypsum levels can be attributed to improved kernel yield and higher oil content. Regarding timing of gypsum application, basal application resulted in the highest oil yield (975 kg/ha), whereas the lowest yield was observed when gypsum was applied at the pod formation stage (651 kg/ha). Similar results have been reported in previous studies, where gypsum application enhanced sulphur availability and amino acid synthesis, thereby increasing oil yield (18, 19).

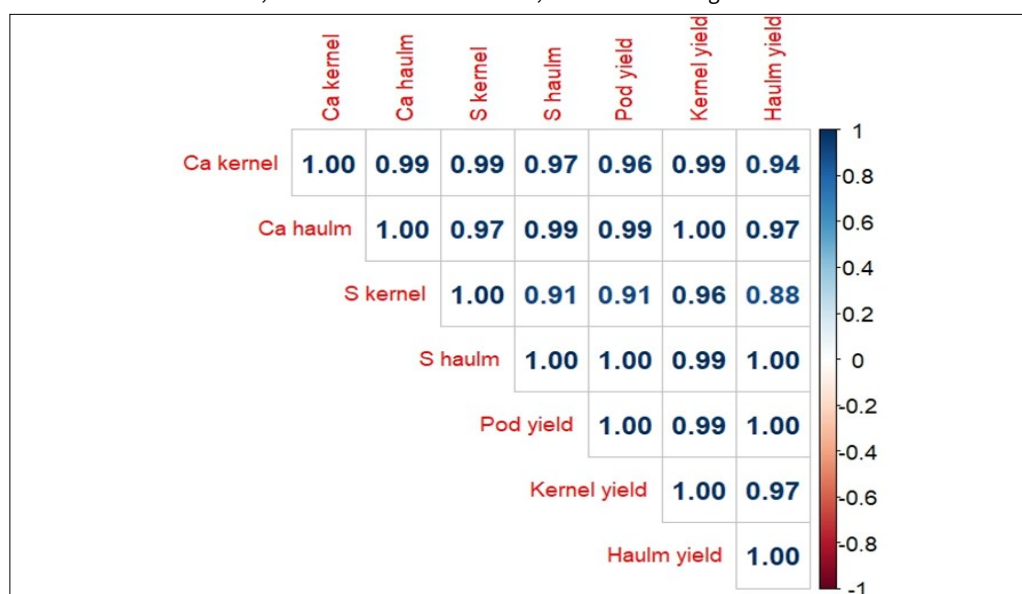
Correlation between nutrient uptake and yield

The correlation between nutrient uptake and yield parameters

Table 4. Effect of different levels and timing of gypsum application on oil content and oil yield of rabi groundnut

Treatments	Oil content (%)	Oil yield (kg/ha)
Levels of Gypsum (A)		
A1-100 kg/ha	42.7	755
A2-200 kg/ha	45.4	846
A3-300 kg/ha	46.2	901
S.E.m. $\pm$	0.7	17
CD ($P=0.05$)	2.0	49
Time of application of Gypsum (B)		
B1-Basal	46.9	975
B2-At pegging stage	46.6	893
B3-At pod formation stage	41.0	651
B4-Split application	44.4	817
S.E.m. $\pm$	0.8	19
CD ($P=0.05$)	2.3	57
Interaction (A×B)		
S.E.m. $\pm$	1.4	33.6
CD ($P=0.05$)	NS	NS

Note: S.E.m. means Standard error of mean, CD means Critical difference, NS means Non-significant.

**Fig. 3.** Correlation matrix of calcium (Ca) and sulphur (S) uptake with pod yield, kernel yield and haulm yield under different gypsum levels.

across gypsum levels is shown in Fig. 3. Calcium uptake in the kernel showed a very positive correlation with calcium uptake in haulm ($r = 0.99$) and with sulphur uptake in both kernel ($r = 0.99$) and haulm ($r = 0.97$). Pod yield ($r = 0.96-0.99$) and kernel yield ($r = 0.99$) also showed strong positive associations with nutrient uptake, while pod yield was perfectly correlated with kernel and haulm yield ($r = 1.00$). These results indicate that under varying gypsum levels, higher uptake of calcium and sulphur was closely linked with greater pod and kernel yields.

The correlation pattern under different timings of gypsum application is presented in Fig. 4. Calcium uptake in kernel had weaker associations with yield ($r = 0.67$ with pod yield and $r = 0.75$ with kernel yield) compared to gypsum levels, but was still strongly correlated with sulphur uptake in kernel ($r = 0.92$). In contrast, calcium and sulphur uptake in haulm exhibited very strong positive correlations with pod yield ($r = 0.99$) and kernel yield ($r = 0.99$). Overall, nutrient uptake in haulm played a more consistent role in explaining yield variation across gypsum application timings, while kernel calcium uptake showed a weaker relationship with yield.

Conclusion

The present study demonstrated that application of gypsum at 300 kg/ha significantly enhanced the growth, yield and oil productivity of groundnut, which was not significantly different

from application at 200 kg/ha. Among the timings, basal application was most effective in meeting the crop's calcium and sulphur requirements, thereby supporting peg initiation, pod filling and kernel quality. Hence, under the agro-climatic conditions of Southern Odisha, applying gypsum at 300 kg/ha as a basal dose is recommended for achieving higher productivity and improved groundnut quality.

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Authors' contributions

BRB, PP and SKP contributed to the conceptualisation of the study. PP, SKP, CHVSP and RSK were involved in the literature search and selection. SKP, CHVSP, PP and BRB carried out data synthesis and thematic organisation. PP, CVSP and SKP prepared the original draft of the manuscript, while PP, SKP, BRB and CVSP were involved in review and editing. BRB and RSK provided



Fig. 4. Correlation matrix of calcium and sulphur uptake with pod yield, kernel yield and haulm yield under different timings of gypsum application.

supervision. All authors have read and approved the final version of the manuscript.

Compliance with ethical standards

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

Ethical issues: None

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