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RESEARCH ARTICLE

Influence of precision nitrogen management in *Rabi* maize and cow pea intercropping system under varied planting proportions in south Odisha

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Abstract

Maize has diverse adaptability under varied agroclimatic conditions that play a pivotal in fulfilling food and feed demand. Maize is sown in wide lines and it shows a sluggish growth at its initial stages facilitating the cultivation of intercrops in between the rows. Among several legumes, cowpea has potential as a grain and fodder, grown as intercrop in maize. There is a need for precise application of nutrients, especially nitrogen (N) in maize cultivation. Considering the above, the current study was carried out during the *Rabi* season of 2023-2024 at the Post Graduate Research Farm of the Centurion University of Technology and Management, Odisha, India. A field trial was laid out in a split-plot design consisting of three intercropping ratios in the main plot and four nitrogen management treatments in the sub-plot. The study revealed that the highest growth attributes, yield parameters and yield of maize were recorded in sole maize and it was followed by maize + cowpea (2:2). However, for N management, the highest growth parameters, yield attributes and yield were noted in GreenSeeker-based treatment and it remained statistically at par with soil plant analysis development (SPAD) threshold-based N application. Among the intercropping systems, the highest values of land equivalent ratio (1.41) and area time equivalent ratio (1.37) were recorded in maize + cowpea (2:3) followed by maize + cowpea (2:2). It may be concluded that sole maize with N management through GreenSeeker can achieve higher maize yields. However, considering the LER, ATER and other competition functions, maize + cowpea (2:2) and N application through GreenSeeker can be the most suitable agronomic option under south Odisha.

Keywords: competition functions; cowpea; GreenSeeker; leaf colour chart (LCC); maize; soil plant analysis development (SPAD); yield

Introduction

Maize (*Zea mays* L.) is a pivotal crop in global agriculture, providing food, animal feed and industrial products that plays a vital part in food security and the economy, particularly in developing countries. Maize is widely cultivated under diverse cropping systems (1). Maize is cultivated with wide row spacing and shows slow vegetative growth during early stages. This creates enough potential to adopt intercropping crops between the rows of maize (2).

Intercropping optimizes resource use, stabilizes yields and enhances farm profitability while promoting sustainable agriculture. An intercropping system supports “SDG 2 (zero hunger), SDG 12 (responsible consumption and production) and SDG 13 (climate action)” by improving soil health, reducing chemical inputs and strengthening food security (3-5). Further manipulation of planting geometry like the adoption of paired-row planting offers more scope for intercropping in maize (6, 7).

Among the intercropping legumes, cowpea (*Vigna unguiculata* L.) has a huge potential as a versatile crop to meets the needs of protein and animal feed. Besides, cowpea is well fit to unfertile soils and can be cultivated in diverse climatic conditions (8). Thus, cowpea can be the most suitable legume in the maize-legume intercropping system (9). Since their interspecific facilitation results in superior resource use and improved productivity from a unit area compared to monocropping, the combination of cereal -legume as intercropping system can be a significant ecological intensification for agricultural sustainability (10). Under the scenario of climate change and agriculture land shrinkage (11), the intercropping system can assure better land use efficiency and crop security for the farmers (12-14).

A successful crop needs the application of nutrients based on the needs of cultivars and the growing situation (15, 16). Cereals like rice, maize and wheat are heavy feeders of soil nutrients and require high doses of fertilizers (17). The recommended dose of fertilizer application may result in either application of excess fertilizers or under fertilization depending on soil fertility status and crop nutrient need (18).

In this scenario, precision nutrient management can analyze the spatial variability of a particular field and recommends the nutrients either through a soil or plant-based approach (19). Maize needs N for photosynthesis, protein synthesis and overall plant development (11). To assure optimal nitrogen use and reduce environmental impact, optical sensors are progressively applied in precision agriculture. This technology helps minimize nitrogen overuse, enhances nitrogen use efficiency and reduces nitrogen runoff, which can harm surrounding ecosystems. When coupled with intercropping practices, optical sensors become even more valuable. There are various optical sensors, decision support systems and leaf colour charts (LCC) developed in recent years for precision nutrient management in maize (20). Optical sensors such as chlorophyll content meters and GreenSeekers are handheld portable devices estimating the chlorophyll index of non-destructive leaves (12). This greenness index in maize can be considered as a threshold value and topdressing of nitrogen is carried out with real-time interpretation (13). As an alternative to these sensors, the LCC is a smart device that enables farmers to find the real-time nitrogen requirement of crops. Integrating these precision nutrient tools in maize cultivation will allow farmers to make proactive and accurate decisions concerning nutrient optimization and application. Based on the above, an experiment was carried to evaluate the precision nitrogen management tools in the maize-cowpea intercropping system under south Odisha.

Materials and Methods

Study area

The trial was conducted at the Post Graduate Research Farm of Centurion University of Technology and Management, Paralakhemundi (18°48′16″ N latitude, 84° 10′48″ E longitude) with an altitude of 145 m above mean sea level in Southern Odisha, India. During the crop growing period, the average weekly maximum and minimum temperature recorded were ranged from 28.4-42.9 °C to 14.5-27.6 °C and maximum and minimum relative humidity ranged from 77-87 % and 38-70 % respectively. The crop received a total rainfall of 88.4 mm and the bright sunshine hours recorded per day ranged between 7.5 and 10.5 hr/day (Table 1). The study was conducted in sandy loam soils with organic carbon of 0.42 %, pH 6.3 and soil available nitrogen (low), phosphorous (medium) and potassium (medium) with values of 226, 12.2 and 131.6 kg/ha respectively.

Experimental details

The trial was laid out in a split-plot design comprising 12 treatment combinations and three replications. The treatment considered in the main plot factor was intercropping ratios C_1: sole maize uniform row, C_2: maize paired row + cowpea (2:2) and C_3: maize paired row + cowpea (2:3) and in subplot factor comprised of different nitrogen management treatments which include N_1: 100 % recommended dose of nitrogen (RDN), N_2: nitrogen management through SPAD-based threshold value at 45, N_3: nitrogen management through GreenSeeker-based normalized difference vegetative index (NDVI) at 0.8, N_4: nitrogen management through LCC value at 4. The recommended dose of fertilizer for maize was 120:60:60 kg/ha of $N:P_2O_5:K_2O$ respectively and for the mixed stands, no additional fertilizers was applied.

Crop management

For experimenting, the land was thoroughly ploughed and good tilth was maintained before sowing of the crop. The experimental plot size was 5 m × 4.5 m (22.5 m^2) each. Further, each treatment plot consisted of 8 rows of maize and in intercropping treatments, 2 and 3 rows of cowpea was sown in between each paired rows of maize. Maize hybrid ‘Bayer DKC 9217’ and cowpea variety ‘KBC 9’ were chosen with the duration of 120 days and 90 days

Table 1. Meteorological data during the crop period from December 2023 to April 2024

Standard week (Duration)	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity		Rainfall (mm)	Bright Sunshine (hr day^{-1})
			Morning (%)	Afternoon (%)		
2nd	31.14	18.3	85.14	63.43	0	6.34
3rd	29.84	19.41	85.86	65.71	0	5.73
4th	28.71	19.34	85.14	70.29	0	6.74
5th	31.62	17.8	85.85	53.57	0	5.94
6th	32.51	20.95	86.14	61.74	0	7.6
7th	33.94	16.98	84.57	49.71	0	8.17
8th	34.42	21.37	82.85	47.85	0	8.32
9th	35.12	21.56	85.62	52.62	0	8.75
10th	35.65	23.81	81.14	45.14	0	8.02
11th	36.44	24.4	82.28	51.14	0	7.68
12th	32.71	22.38	84.71	62.42	60.7	7.67
13th	37.98	23.45	81	46.57	0	8.77
14th	39.1	26.68	79.28	39.28	0	8.74
15th	38.54	20.11	77.85	38.28	0	8.98
16th	42.24	26.81	77.42	42.85	0	8.54
17th	42.24	29.95	77	41.28	1.2	8.91
18th	41.9	28.3	79	50.14	0	8.97
19th	36.63	25.23	83.57	57.43	93.4	8.73
20th	36.5	25.9	82.7	62.00	24.00	8.14
21st	36.92	27.81	81.57	62.14	0.3	9.11

Data source: Agro-Meteorological Observatory, Centurion University of Technology and Management, Paralakhemundi, Odisha, India.

respectively. Sole maize was sown with the spacing of 60 cm × 25 cm by dibbling method and paired row planting of maize was done with a spacing of 30/90 cm × 25 cm there by maintaining 30 cm between the two rows of a pair and 90 cm between the two pairs of maize. Followed by sowing, one irrigation was given for proper germination and better plant establishment. Two hand weedings were adopted at 15 and 45 DAS and one spraying of herbicide combination of Tembotrione + Atrazine was applied at 25 DAS for weed management. During the crop growing period, the fall armyworm pest was observed in the maize crop at 45 DAS and Chlorpyriphos was sprayed @2 mL per litre of water was at 35 DAS.

Data collection and statistical analysis

The biometric observations of maize like plant height, leaf area index and dry matter accumulation were recorded randomly from five plants in each plot by leaving two border lines from the edge of the plot. Ten random plants were selected for the calculation of the yield attributes like number of cobs/plant, cob length (cm), cob girth (cm), grain rows/cob, number of grains/row and test weight (g). The data were analysed statistically by using analysis of variance (ANOVA) and the standard error of means (S. Em. ±) and critical difference at 5 % probability level of significance. Further, the Excel software (Microsoft Office Home and Student version 2019-en-us, Microsoft Inc., Redmond, Washington, USA) was used for statistical analysis. Competition functions were calculated such as land equivalent ratio (LER), aggressivity (A), relative crowding coefficient (K), area time equivalent ratio (ATER) and competitive ratio by considering the following equations.

Land equivalent ratio (LER)

Following is the formula of land equivalent ratio (LER) for an additive series (21).

$$LER = \frac{Yab}{yaa} + \frac{Yba}{Ybb} = La + Lb \qquad \text{(Eqn. 1)}$$

Where, *Yab* and *Yba* are the intercrop yields of both crops "*a*" and "*b*" and *Yaa* and *Ybb* are the yields in their respective sole plots. *La* and *Lb* is the land equivalent ratio of crop "*a*" and "*b*" whereas, *LER* is for the combined intercrop yield.

The *LER* value is more than 1 indicates yield benefits and when it equals to 1, it specifies neither benefit or loss while adopting the intercropping system.

Area time equivalent ratio (ATER)

ATER signifies the performance of land use efficiency over time and it was known that LER amplifies the resource use and ATER underestimates the same over time (22). By using the following formula, the ATER can be calculated.

$$ATER = \frac{(Rya \times ta) + (Rya \times tb)}{T} \qquad \text{(Eqn. 2)}$$

Where, *RYa* and *RYb* are the relative yields of crop species "*a*" and "*b*" whereas *ta* and *tb* are the time periods of crop species "*a*" and "*b*" for which they are in field. T is the time period of the intercropping system.

Comparative ratio (CR)

$$CRa = \left(\frac{LER\ a}{LERb}\right) \times \left(\frac{Zba}{Zab}\right) \qquad \text{(Eqn . 3)}$$

$$CRb = \left(\frac{LER\ b}{LERa}\right) \times \left(\frac{Zab}{Zba}\right) \qquad \text{(Eqn . 4)}$$

Where, land equivalent ratios of crops are *LERa* and *LERb* "*a*" and "*b*" and *Zab* and *Zba* are the sowing proportions of the crops in the intercropping treatments. However, *CRa* and *CRb* are the competitive ratios of the crop species "*a*" and "*b*" respectively (23).

Aggressivity (A)

The aggressivity denotes the aggressiveness of crops in the mixed stand and the following equation presents the aggressivity of an intercropping system (24).

$$Aab = \frac{Yab}{Yaa \times Zab} - \frac{Yba}{Ybb \times Zba} \qquad \text{(Eqn. 5)}$$

Yab and *Yba* denotes the productivity of crop "*a*" and "*b*" in intercropping system and Y*aa* and Y*bb* are the productivity of crop "*a*" and "*b*" in their pure stand. *Aab* represented the aggressivity of crop "*a*" in existence with crop "*b*". However, *Zab* and *Zba* are the proportion of crop "*a*" and "*b*" in intercropping system, respectively.

Relative crowding coefficient (K)

The relative crowding coefficient is an important competition function that signifies the competitiveness of crops in the mixed stand and can be computed by the following formula (25).

$$Kab = \frac{Yab \times Zab}{(Yaa - Zab) \times Zba} \qquad \text{(Eqn. 6)}$$

$$Kba = \frac{Yba \times Zab}{(Ybb - YBa) \times Zba} \qquad \text{(Eqn. 7)}$$

$$\text{Product of RCC} = Kab \times Kba \qquad \text{(Eqn. 8)}$$

Where, *Kab* and *Kba* denotes RCC values of crop species "*a*" and "*b*". *Yab* and *Yba* are the yields of crop "*a*" and "*b*" in intercropping system and *Yaa* and *Ybb* are the yields of crop "*a*" and "*b*" in sole cropping. However, *Zab* and *Zba* are the sowing proportion of crop "*a*" and "*b*" in intercropping system, respectively.

Results and Discussion

Growth attributes

The growth attributes of maize showed a significant variation concerning intercropping ratios and nitrogen levels (Table 2). Among the cropping systems, sole maize recorded the tallest plants (230.6 cm), dry matter production (1498 g/m²) and leaf area index (4.67), which were significantly higher than other intercropped treatments, namely, maize PR + cowpea (2:2) and maize PR + cowpea (2:3). The reduction in growth attributes under intercropping systems might be due to competition for resources such as nutrients, water and light between maize and cowpea. The lower dry matter production and LAI in intercropped treatments revealed that cowpea might compete with maize for essential resources in the mixed stands. These findings align with earlier research, where sole maize exhibited higher growth due to the absence of interspecies competition (26-28).

Nitrogen management significantly influenced the growth parameters of maize. The highest plant height (243.6 cm) and dry matter accumulation (1796 g/m²) and leaf area index (5.06) were recorded with GreenSeeker-based nitrogen application. Further, in the case of plant height, this treatment remained on par with SPAD-based nitrogen management and was significantly superior to all other treatments. However, the treatment GreenSeeker-based nitrogen application registered the highest dry matter production and LAI and it was significantly superior to remaining treatments. The enhanced growth parameters under this treatment might be attributed to precise nitrogen application treatments based on crop requirements and greater splits resulted in a continuous supply of the primary nutrient leading to better nutrient uptake and utilization. The lowest plant height (193.5 cm), dry matter accumulation (1118 g/m²) and leaf area index (3.55) were observed in LCC-based nitrogen application, which remained significantly inferior to other nitrogen management treatments. The lower growth under the LCC -based N management might be deprived due to underestimation of N requirement resulting in insufficient nitrogen supply and restricting the vegetative growth of maize. These results are consistent with previous findings that suggest precision nitrogen management strategies like GreenSeeker improve crop growth by optimizing nutrient availability (29-31). The interaction between intercropping and nitrogen management did not show any significant difference in expression of plant height, dry matter accumulation and leaf area index (32).

Table 2. Effect of intercropping system and nitrogen management on growth attributes of maize

Treatments	Plant height (cm) at harvest	Dry matter accumulation (g/m²) at harvest	Leaf area index at 60 DAS
Intercropping system			
Sole maize	230.64	1498	4.67
Maize PR + Cowpea (2:2)	215.92	1418	4.32
Maize PR + Cowpea (2:3)	210.21	1360	4.20
S. Em. ±	3.82	21.71	0.09
CD at 5 %	15.01	85.23	0.36
Nitrogen level			
100 % RDF	214.21	1288	4.30
SPAD	224.42	1499	4.69
GreenSeeker	243.64	1796	5.06
LCC	193.57	1118	3.55
S. Em. ±	6.82	32.16	0.12
CD at 5 %	20.26	95.53	0.36
Intercropping system × Nitrogen level			
S. Em. ±	11.81	55.70	0.21
CD at 5 %	NS	NS	NS

Yield attributes

The yield attributes of maize, namely cobs per plant, grains per cob, test weight, cob weight, cob length and cob girth, were significantly influenced by intercropping ratios and nitrogen management (Table 3). However, some parameters, such as test weight, cob length and cob girth, were not significantly affected by intercropping treatments, however, the interaction effect between intercropping and nitrogen management was non-significant for most traits except number of grains/cob and cob weight.

Among different cropping systems, sole maize recorded the highest values for most yield attributes. The highest number of cobs/plant (1.54), grains/cob (255.9), cob weight (288.5 g) and cob length (22.5 cm) were

Table 3. Effect of intercropping system and nitrogen management on yield attributes of maize

Treatments	Cobs per Plant	Grains per Cob	Test weight (g)	Weight of cob (g)	Length of cob (cm)	Girth of Cob (cm)
Intercropping system						
Sole maize	1.54	255.9	24.8	288.5	22.5	12.8
Maize PR + Cowpea (2:2)	1.49	241.4	24.8	273.7	21.6	12.1
Maize PR + Cowpea (2:3)	1.46	237.3	24.6	269.8	21.4	11.8
S. Em. ±	0.02	4.25	1.17	4.32	1.21	0.34
CD at 5 %	0.08	17.12	NS	17.35	NS	NS
Nitrogen level						
100 % RDF	1.45	230.8	24.2	265.3	21.3	12.3
SPAD	1.51	241.9	24.9	272.7	23.6	12.9
GreenSeeker	1.62	293.1	25.5	293.2	24.5	13.5
LCC	1.36	215.1	24.1	254.4	20.1	11.7
S. Em. ±	0.02	6.48	1.21	8.23	1.42	0.41
CD at 5 %	0.06	19.66	NS	27.75	4.21	1.22
Intercropping system × Nitrogen level						
S. Em. ±	0.03	4.29	0.19	12.1	5.24	0.61
CD at 5 %	0.10	12.75	NS	NS	NS	NS

recorded in sole maize, which was statistically at par with maize PR + cowpea (2:2) and significantly superior to maize PR + cowpea (2:3). Sole maize registered its superiority in expression of yield attributes might be due to the absence of interspecies competition, which resulted in better resource utilization and higher reproductive growth. Further, the optimum vegetative growth in sole maize might enhance the highest photosynthate assimilation to cobs during the reproductive phase and reflect superior performance. Among the intercropped treatments, maize PR + cowpea (2:2) performed better than maize PR + cowpea (2:3) in most yield parameters. However, the difference between the two intercropping systems was nonsignificant for test weight, cob length and cob girth, suggesting that while intercropping reduced overall yield attributes, it did not drastically affect kernel weight and cob size. The decrease in yield attributes under intercropping might be attributed because of competition between maize and cowpea for light, nutrients and moisture, which restricted cob development. These results are consistent with earlier studies showing a similar trend of intercropping systems in reducing yield attributes in maize due to interspecies competition (26, 29).

Nitrogen management significantly influenced all yield attributes of maize. The superior values of cobs/plant (1.62), grains/cob (293.1), test weight (25.5 g), cob weight (293.2 g), cob length (24.5 cm) and cob girth (13.5 cm) were recorded in GreenSeeker-based nitrogen application. Further, it was significantly superior to all other nitrogen levels, except for cob length and girth, where it was statistically similar with SPAD-based N application and 100 % RDF. Such results highlighted the benefits of precision nitrogen application in optimizing maize yield attributes. The increased grain number, cob weight and size under GreenSeeker-based treatment could be attributed due to improved N use efficiency, leading to better nutrient uptake, thereby enhancing the number of cobs/plant, enhanced grain filling and overall development of maize cob. Conversely, the lowest yield attributes were recorded in LCC-based nitrogen application, which produced significantly lower values of cobs per plant (1.36), grains per cob (215.1), test weight (24.1 g), cob weight (254.4 g), cob length (20.1 cm) and cob girth (11.7 cm). The reduced yield attributes under this treatment indicated that LCC-based nitrogen application might guide suboptimal nitrogen availability during critical growth stages, leading to poor cob development. The results align with previous studies (29-31).

The interaction between intercropping systems and nitrogen levels was non-significant for most of the yield attributes except the number of cobs per plant and grains/cob. The highest number of cobs/plant and grains/cob were recorded in the combination of sole maize with GreenSeeker-based N application and remained significantly superior to all other treatment combinations (Fig. 1). However, the inferior values of yield attributes among the treatment combinations were noted in maize PR + cowpea (2:3) and LCC-based nitrogen application (33).

Yield

Among the different cropping systems, sole maize recorded the highest grain (5367.83 kg/ha), stover (10802 kg/ha) and biological yields (16169 kg/ha) and it was significantly superior to other intercropped treatments (Table 4). The maize PR + cowpea (2:2) system produced the second-best grain, stover and biological yields of maize 4743 kg/ha, 10078 kg/ha and 14821 kg/ha respectively and it was statistically at par with maize PR + cowpea (2:3) cropping system with grain yield 4496 kg/ha, stover yield 9679 kg/ha and biological yield 14175 kg/ha. The yield reduction of maize under the intercropping systems could be attributed because of the interspecies competition for essential resources in the mixed stand. Maize yield reduction was comparatively less in maize PR + cowpea (2:2) than maize PR + cowpea (2:3) system, suggesting that a balanced maize-to-cowpea ratio (2:2) was less competitive than a higher cowpea proportion (2:3). These results align with previous research indicating that sole cropping results in higher maize yields due to the absence of interspecies competition (26, 29, 33).

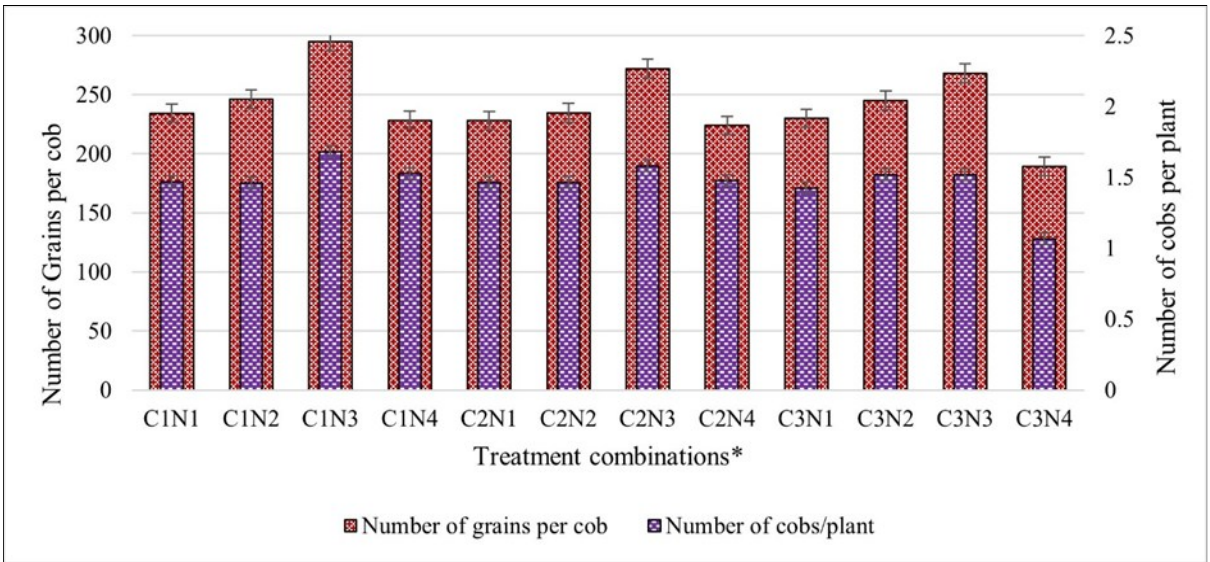

Fig. 1. Interaction effect of intercropping system and nitrogen level on yield attributes of maize. *For treatment details refer materials and methods section.

Table 4. Effect of intercropping ratios and nitrogen management on yield of maize

Treatments	Yield (kg/ha)		
	Grain yield	Stover yield	Biological yield
Intercropping system			
Sole maize	5366.83	10832.42	16169.25
Maize PR + Cowpea (2:2)	4743.58	9818.25	14821.83
Maize PR + Cowpea (2:3)	4496.67	9679.25	14175.92
S. Em. ±	83.27	207.51	243.97
CD at 5 %	326.92	814.68	957.79
Nitrogen level			
100 % RDF	4764.33	9268.33	14032.67
SPAD	5118.11	10281.22	15399.33
GreenSeeker	5505.00	13146.89	18651.89
LCC	4088.67	8050.11	12138.78
S. Em. ±	49.45	455.91	471.12
CD at 5 %	146.90	1354.38	1399.57
Intercropping system × Nitrogen level			
S. Em. ±	85.65	789.66	816.01
CD at 5 %	252.44	2245.85	2448

N management significantly influenced the yields of maize. The highest grain yield (5505.00 kg/ha), stover yield (13146.89 kg/ha) and biological yield (18651.89 kg/ha) were recorded under GreenSeeker-based nitrogen application, which produced significantly higher yields than all other nitrogen levels. The improved yield attributes under the aforesaid treatment suggested that the precision nitrogen management through GreenSeeker optimized nutrient uptake, leading to higher biomass production and grain formation. Conversely, the lowest grain yield (4088.67 kg/ha), stover yield (8050.11 kg/ha) and biological yield (12138.78 kg/ha) were recorded in LCC -based nitrogen application. The reduced yield under LCC-based nitrogen management might be due to inadequate or delayed nitrogen supply, which restricted vegetative and reproductive growth. The SPAD-based nitrogen application recorded moderate yields, with grain yield (5118.11 kg/ha), stover yield (10281.22 kg/ha) and biological yield (15399.33 kg/ha), performing significantly superior to 100 % RDF and LCC-based nitrogen management but lower than GreenSeeker-based N application. The results further signifies that the use of optical sensors like GreenSeeker and SPAD meter may optimize the nitrogen requirement in low nitrogen soils through real time assessment of crop required nutrient in appropriate time and quantity. This precision nitrogen management practices can guide farmers for precise application of nitrogenous fertilizer which may result in optimizing the input cost and enhancing crop yields. These results are in line with previous findings of earlier researchers (29-31).

The interaction between intercropping ratio and nitrogen level showed a significant effect on grain yield, stover yield and biological yield of maize (Fig. 2). The highest grain yield, stover yield and biological yield were recorded in sole maize with GreenSeeker-based nitrogen management and it registered its significant superiority over remaining treatment combinations (34).

Competition functions

The total LER values for all treatment combinations were higher than 1, indicating that intercropping was more advantageous than sole cropping for land utilization (Table 5). Among treatment combinations, the highest total LER (1.41) was recorded under C_3N_1 (maize PR + cowpea (2:3) with 100 % RDF), followed by C_3N_2 (1.35) and C_2N_1 (1.34). This suggests that the maize PR + cowpea (2:3) system utilized land more efficiently than the maize PR + cowpea

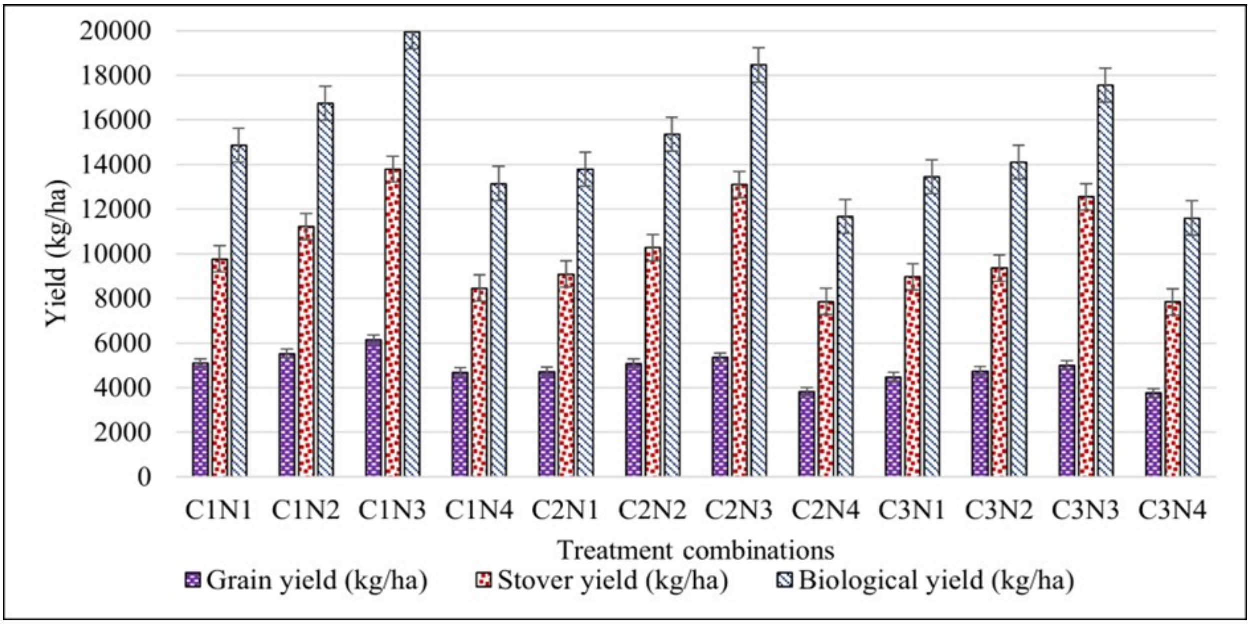

Fig. 2. Interaction effect of intercropping system and nitrogen level on yield of maize. *For treatment details refer materials and methods section.

Table 5. Effect of intercropping ratios and nitrogen levels on land equivalent ratio, area time equivalent ratio, relative crowding coefficient

Land equivalent ratio (LER)				ATER	Relative crowding coefficient		
Treatment combinations	Maize	Cowpea	Total		RCC m	RCC c	RCC product
C_2N_1	0.93	0.42	1.34	1.20	6.27	1.43	8.95
C_2N_2	0.92	0.39	1.31	1.29	5.75	1.30	7.47
C_2N_3	0.87	0.40	1.27	1.29	3.34	1.33	4.44
C_2N_4	0.81	0.43	1.24	1.10	2.18	1.48	3.23
C_3N_1	0.88	0.53	1.41	1.28	5.52	1.49	8.20
C_3N_2	0.86	0.49	1.35	1.37	4.53	1.30	5.88
C_3N_3	0.81	0.47	1.29	1.30	3.27	1.20	3.93
C_3N_4	0.80	0.51	1.31	1.23	3.00	1.40	4.20

(2:2) system. The maize LER was highest in C_2N_1 (0.93) and C_2N_2 (0.92), indicating that maize had a competitive advantage in the 2:2 intercropping system with 100 % RDF and SPAD-based nitrogen application. On the other hand, the cowpea LER was highest in C_3N_1 (0.53), suggesting that cowpea benefitted more under the 2:3 intercropping system with 100 % RDF. These results demonstrated that closer intercropping (2:3) favoured cowpea growth, while the 2:2 system facilitated maize growth. Such results might be obtained because of complementary and competitive effects among species (34-36).

The ATER values were ranged between 1.10 and 1.37, with the highest value recorded in C_3N_2 (1.37) which was closely followed by C_2N_2 (1.29) and C_2N_3 (1.29). The higher ATER values in C_3N_2 and C3N1 suggested that the maize PR + cowpea (2:3) system provided a better balance in resource utilization efficiency over time than the 2:2 maize + cowpea intercropping system (26, 28). The relative crowding coefficient (RCC) indicates the degree to which one crop dominates another in an intercropping system. The RCC values for maize (RCCm), cowpea (RCCc) and their product (RCC product) varied significantly among treatments. The highest RCC product (8.95) was observed in C_2N_1 (maize PR + cowpea (2:2) with 100 % RDF, followed by C_3N_1 (8.20), indicating a strong competitive advantage for maize. The RCCm values were highest in the treatment combinations of C_2N_1 (6.27) and C3N1 (5.52), showing that maize was more dominant in combination. The RCCc values of cowpea varied from 1.20 to 1.49, with the highest values in C_3N_1 (1.49) and C_2N_4 (1.48), indicating the competitiveness of cowpea under nitrogen-stressed conditions (LCC-based nitrogen application) (30).

Aggressivity measures the dominance of one species over another in an intercropping system. A positive aggressivity value for maize and a negative value for cowpea observed in the study indicated that maize was the dominant crop in the system, however, cowpea was the dominated species (Table 6). The highest aggressivity value for maize (0.72) was observed with the treatment combination C_2N_1 (maize PR + cowpea (2:2) with 100 % RDF) and C_2N_2 (maize PR + cowpea (2:2) with SPAD-based nitrogen application), specified that maize had the highest competitive advantage with these treatment combinations. The lowest aggressivity value for maize (0.42) was recorded in C_3N_4 (maize PR + cowpea (2:3) with LCC-based nitrogen application), indicating a more balanced competition between maize and cowpea. The negative aggressivity values for cowpea ranged from -0.42 (C_3N_4) to -0.73 (C_2N_2), confirming that cowpea was always the dominated crop species in the intercropping system studied. The results showed that maize was the dominant crop in all intercropping systems and the dominance was expressed more under the 2:2 proportion with higher nitrogen availability (100 % RDF and SPAD-based application). However, in the 2:3 intercropping system and under lower nitrogen levels (LCC-based nitrogen application), cowpea was able to compete more effectively (26, 28).

Table 6. Effect of intercropping system and nitrogen level on aggressivity and competitive ratio

Aggressivity			Competitive ratio	
Treatment combinations	Maize	Cowpea	Maize	Cowpea
C_2N_1	0.72	-0.72	1.11	0.90
C_2N_2	0.72	-0.73	1.17	0.86
C_2N_3	0.67	-0.67	1.09	0.92
C_2N_4	0.60	-0.60	0.96	1.05
C_3N_1	0.48	-0.48	1.25	0.80
C_3N_2	0.49	-0.49	1.30	0.77
C_3N_3	0.46	-0.46	1.29	0.78
C_3N_4	0.42	-0.42	1.17	0.85

The competitive ratio (CR) further quantifies the dominance of one crop over another. CR value greater than 1 indicates that a crop is more competitive, while a CR value less than 1 suggests that the crop is less competitive. The highest CR for maize (1.30) was noted with C_3N_2 (maize PR + cowpea (2:3) with SPAD-based nitrogen management), which was closely followed by C_3N_3 (1.29) and C_3N_1 (1.25). The lowest CR for maize (0.96) was found in C_2N_4 (maize PR + cowpea (2:2) with LCC-based nitrogen application), showing that maize was less competitive under lower nitrogen availability. The highest CR for cowpea (1.05) was recorded in C_2N_4 (Maize PR + Cowpea (2:2) with LCC-based nitrogen application), suggesting that cowpea could compete more effectively when nitrogen levels were low (28, 35-38).

Conclusion

The present study demonstrated that both nutrient management strategies and intercropping systems significantly influenced the growth and productivity of maize when intercropped with cowpea. Among the nutrient management tools, GreenSeeker-based nitrogen management emerged as the most effective, resulting in superior growth parameters, yield attributes and grain yield. Regarding intercropping systems, sole maize recorded the highest yield, while the 2:2 maize–cowpea intercropping system offered a promising initiative between productivity and efficient resource use. Based on these findings, it is recommended that GreenSeeker-guided nitrogen application can be promoted among farmers to enhance nitrogen use efficiency and yield outcomes. Additionally, intercropping maize with cowpea in a 2:2 row proportion can be adopted as a sustainable and productive cropping strategy under south Odisha conditions.

Moreover, the future research should focus on the long-term impacts of precision nutrient management tools on soil health, the economic feasibility for smallholders and their performance across diverse environments and cropping systems. This will help in scaling up precision agriculture practices tailored to the needs of small and marginal farmers.

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Authors' contributions

SM and NM carried out conceptualization; SM, MS and NM done methodology; SM, MS, RSK and DJG guided in validation; NM, MS, SR, RKM and KRH has participated in the data analysis; NM, KRH, RKM, MS, SM and SR worked in data curation; NM, MS, SM, KRH, DJG and SR performed in writing- original draft paper; NM, DJG, RKM, RSK and KRH participated in writing - review and editing; SM, MS, RSK and DJG has done supervision. All authors have read and agreed to the published version of manuscript.

Compliance with ethical standards

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

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