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RESEARCH ARTICLE

Crop growth performance in a rice-maize cropping system under conservation agriculture and nutrient management

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Abstract

Reduction in crop growth potential is major hurdle in reaching the desired crop productivity under rice-maize (RM) cropping system. To address the issue, the experiment was conducted at Indian Council of Agricultural Research-Central Rice Research Institute (ICAR-CRRI), Cuttack during 2022-23 and 2023-24 with four production systems: Conventional + Sole Crop (CSC), Conventional + Inter Crop (CIC), Conservation Agriculture + Sole Crop (CASC) and Conservation Agriculture + Inter Crop (CAIC) under three nutrient management strategy: Recommended dose of fertilizer (RDF) (N_R), 25 % N (N_{25}) and 50 % N (N_{50}) based substitution of RDF with FYM (farm yard manure) using split plot design. The results reflect that the overall crop growth was significantly affected by both production systems and nutrient management practices. The plant height, leaf area index (LAI) and dry matter accumulation (DMA) were found higher under conventional system. The N_{25} and N_{50} performed better than N_R though not to a significant extent. The experiment concludes that substituting inorganic fertilizers with organic sources and conservation agriculture practices can enhance the crop growth under RM cropping system.

Keywords: conservation agriculture; conventional; intercropping; nutrient management

Introduction

The increasing pressure on agricultural systems to meet the demands of a growing population while preserving environmental quality has emphasized the need for sustainable farming practices (1-3). In South Asia and similar agro-ecological regions, the RM cropping system has emerged as a crucial rotation with over 1.5 m ha acreage with its high productivity potential (80-90 % attainable yield) and adaptability (4). However, conventional agricultural practices like conventional tillage, residue burning have led to declining soil health, reduced input-use efficiency and stagnating yields (5). Intercropping and crop rotation, especially of legumes and maize (6), are promising approaches to enhance crop productivity (7). Their contrasting photosynthetic pathways offer complementary advantages (8).

Conservation agriculture (CA), characterized by minimal soil disturbance, crop residue retention and crop diversification (9, 10) offers a promising alternative to address these challenges (11). When integrated with nutrient management strategies (12), CA can enhance nutrient uptake, improve soil structure (13) and optimize crop growth (14). Despite its potential, empirical evidence on the combined effects of CA and nutrient management on crop growth dynamics, particularly in RM systems, remains limited.

In India, efforts to develop, refine and disseminate CA technologies have been ongoing for nearly two decades, with significant progress achieved despite several constraints (11). When CA practices are taken up it is also necessary to look into nutrient management techniques for better nutrient availability and uptake by the crop (15). To enhance the rice productivity, improved nutrient management options are required (16). Results may be further improved when combined with stress tolerant cultivars, even under farmers' field conditions (17). The RM cropping system demands a higher quantity of supplementary nutrient application as compared to other cropping systems, both crops being exhaustive in nature. Irrational use of chemical fertilizers harm soil health and leads to reduced crop productivity (18).

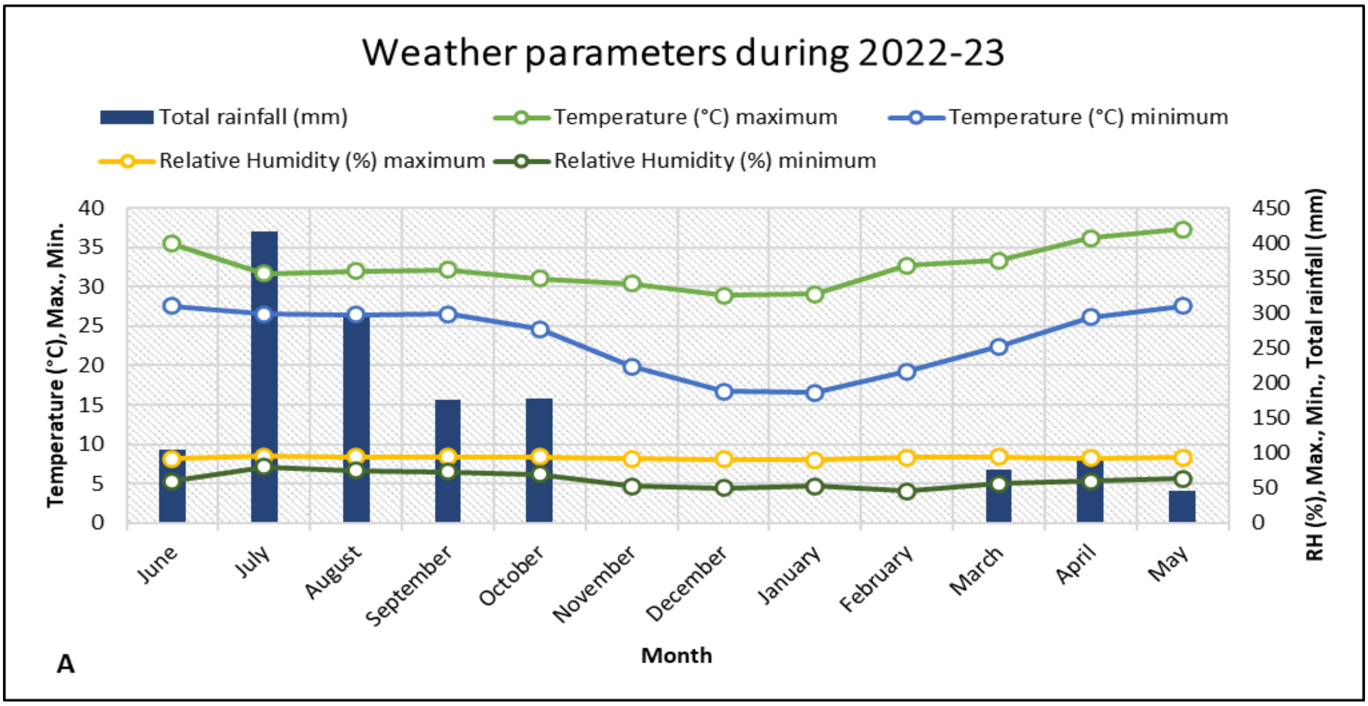
This study aims to evaluate the response of crop growth parameters to different CA and nutrient management practices in a RM cropping system. By assessing key growth indicators such as plant height, biomass accumulation and LAI, this research seeks to generate insights that can inform sustainable intensification strategies and improve resource-use efficiency in the RM cropping system.

Materials and Methods

Details of experiment

The experiment was conducted at the Institute Research Farm of the ICAR-CRRI, in Cuttack, Odisha during the wet and dry season of two consecutive years (2022-23 and 2023-24). The weather parameters studied during the crop growth period were given in

Fig. 1A-B. The experiment was laid out using a split plot design with 12 treatments replicated thrice. In the main plot, four production systems, Conventional + Sole Crop (CSC), Conventional + Inter Crop (CIC), Conservation Agriculture + Sole Crop (CASC) and Conservation Agriculture + Inter Crop (CAIC) was taken and in the sub-plot, three nutrient management treatments were taken up, RDF (N_R), 25 % N based substitution of RDF with FYM(N_{25}) and 50 % N based substitution of RDF with FYM (N_{50}).



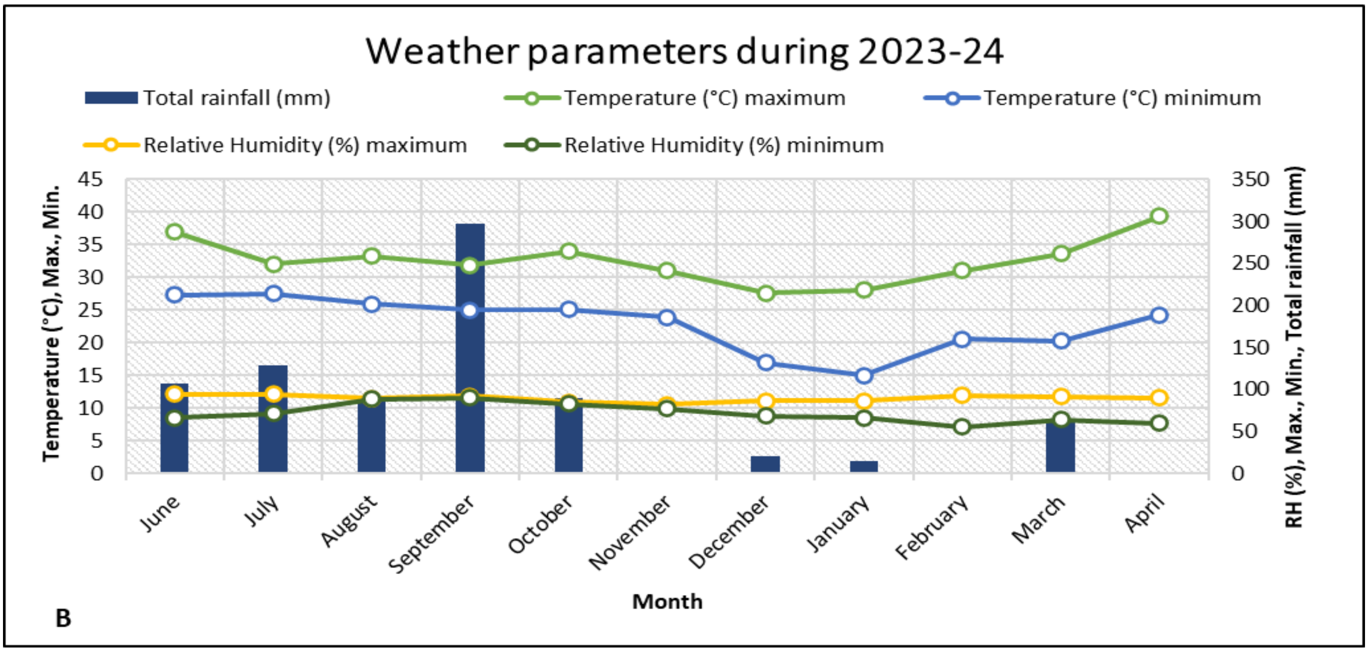


Fig. 1. Weather parameters recorded during the crop growth period: (**A**) Wet and dry season (2022-23); (**B**) Wet and dry season (2023-24).

Table 1. Crop management practices as per the treatment

Management practice	Rice		Maize		Maize + Groundnut	
Tillage	Conventional	No	Conventional	No	Conventional	No
Residue retention	No residue	No residue	No crop residue	30 % rice crop residue as stubble	No crop residue	30 % rice crop residue as stubble
Sowing method	Direct seeding with 20 cm row spacing		Direct seeding with 60 cm ×15 cm spacing		Direct seeding maize with 60 cm ×15 cm spacing and in between rows groundnut sowing with 10 cm plant spacing	
Nutrient management						
N_R (RDF)	80:40:40 (NPK)		150:50:50 (NPK)		150:50:50 +10:20:20 (NPK)	
N_{25}	25 % N based substitution with FYM					
N_{50}	50 % N based substitution with FYM					
Number of replications: 3						

The sowing was done on 10.06.2022 and 10.06.2023 for rice which was harvested on 18.10.2022 and 20.10.2023 respectively. For maize the sowing was done during 15.12.2022 and 15.12.2023 and harvested on 30.03.2023 and 30.03.2024 respectively. A medium duration (130 –135 days) variety of rice (CR Dhan 314) and maize hybrid (4226) having 105 to 110 days' crop duration was taken as test variety. The details of crop management practices as per the treatments are presented in Table 1.

Observations recorded

The plant height, number of leaves, leaf area and DMA were recorded at different crop growth stages. LAI was calculated by dividing average leaf area per plant by the ground area occupied per plant.

$$\text{LAI} = \frac{\text{Total leaf area plant}^{-1}\text{ (cm)}}{\text{Total ground area (cm)}} \quad \text{(Eqn. 1)}$$

DMA recorded at different stages was used to calculate the crop growth rate (CGR).

$$\text{CGR (g m}^{-2}\text{ day}^{-1}) = W_2 - W_1/t_2 - t_1 \quad \text{(Eqn. 2)}$$

Where, W_1 and W_2 are dry weight (g) of plants at time t_1 and t_2 respectively, t_1 and t_2 are the time interval in days.

The DMA data recorded at different durations were also used to compute the relative growth rate (RGR). The RGR was calculated (19) as follows:

$$\text{RGR (g g}^{-1}\text{ day}^{-1}) = (\ln W_2 - \ln W_1) / (t_2 - t_1) \quad \text{(Eqn. 3)}$$

Where, W_1 and W_2 are dry weight (g) of plants at time t_1 and t_2 respectively, t_1 and t_2 are the time interval in days.

Results and Discussion

Rice

The plant growth parameters of rice—plant height at harvest, DMA and LAI (Table 2)- varied across production systems and nutrient management practices over two consecutive years (2022 -23 and 2023-24).

Plant height at harvest

During 2022-23 at harvest, the greatest plant height (120.44 cm) was observed with CSC which was statistically at par with CIC but significantly higher (111.56 cm, 113.44 cm) than CASC and CAIC respectively. Conventional sole crop (CSC) resulted maximum (124.67 cm) plant height at harvest during 2023-24. This treatment differed significantly from CIC and significantly higher (108.50 cm, 112.28 cm) than CASC and CAIC respectively. The intercropping during the dry season could not significantly influence the plant height of rice. This may be due to greater soil compaction resulting in lower root growth and ultimately affecting the shoot growth of rice plant (20). The impact of nutrient management (N_R, $N_{25,}$ and N_{50}) on plant growth was statistically non-significant (NS). This may be because, although the source of nutrient differed ,the rate of application was the same (21).

Leaf area index

The LAI of rice at 90 days after sowing (DAS) shows that CIC recorded the highest LAI (4.99 in 2022-23), whereas CA with intercrop (CAI) had the lowest (3.76 in 2022-23). The influence of nutrient management on LAI was non-significant at all growth stages. However, numerical trends suggest that at 90 DAS, LAI was highest under N_{25}(4.67 in 2023-24), suggesting that 25 % N based substitution promoted better canopy development.

Dry matter accumulation

Dry matter accumulation (DMA) in rice varied significantly across production systems and nutrient management practices during both years of study. In 2022-23, the highest DMA (923.33 g m^{-2}) was recorded under CSC, which was statistically at par with CIC but significantly higher than CASC and CAIC. Among nutrient management treatments, all showed significant differences, with the maximum DMA (879.17 g m^{-2}) under 25 % N substitution (N_{25}), statistically at par with the recommended dose (N_R). The N_R and N_{50} treatments did not differ significantly. Similar results were found in 2023-24.

Interactions between production systems and nutrient

Table 2. Effect of production system (PS) and nutrient management (N) practices over plant growth parameters of rice

Treatment	Plant height at harvest (cm)		LAI (at 90 DAS)		DMA (g m^{-2})	
	2022–23	2023–24	2022–23	2023–24	2022–23	2023–24
PS						
Conv. + Sole crop (CSC)	120.44	124.67	4.99	4.67	923.33	1405.56
Conv. + Intercrop (CIC)	118.33	120.11	4.57	4.38	904.44	1173.33
CA + Sole crop (CASC)	111.56	108.50	3.77	3.81	834.44	793.33
CA + Intercrop (CAIC)	113.44	112.28	4.09	4.18	784.44	756.67
SE(m) ±	2.25	1.29	0.33	0.25	7.093	22.553
CD (*p*=0.05)	NS	4.49	NS	NS	24.54	78.04
N						
N_R	115.42	115.54	4.39	4.10	853.33	1007.50
N_{25}	116.75	117.17	4.39	4.67	879.17	1036.67
N_{50}	115.67	116.46	4.29	4.02	852.50	1052.50
SE(m) ±	1.06	0.48	0.33	0.21	8.620	12.214
CD (*p*=0.05)	NS	NS	NS	NS	25.16	35.64
Interaction (CD (*p*=0.05))						
PS*N	NS	NS	NS	NS	47.73	97.02
N*PS	NS	NS	NS	NS	50.32	71.29

Conv.: Conventional; **CA**: Conservation agriculture; **N_R**: RDF; **N_{25}**: 25 % Nitrogen substitution with FYM; **N_{50}**: 50 % Nitrogen substitution with FYM.

management were significant (CD at 5 %: 97.02 and 71.29). The highest overall DMA (1560 g m^{-2}) occurred in CSC with N_{25} significantly surpassing all other treatment combinations. The results indicate the residual impact of intercropping with legumes in dry season on DMA of wet season crop (22, 23). This may be due to better nutrient mobilization and good soil physical properties assisting in greater photosynthetic accumulation (24).

Crop growth rate

The highest CGR (Fig. 2A-B) was observed in CA with sole crop (CAS) (15.50 g m^{-2} day^{-1}), which was at par with CIC (14.60 g m^{-2} day^{-1}) in 2022-23 while in second year the CI and CSC achieved highest during this period. At 60 DAS, CGR was highest under N_{25} (14.80 g m^{-2} day^{-1} in 2022-23), followed closely by N_R, while N_{50} recorded the lowest CGR (13.14 g m^{-2} day^{-1} in 2022-23). At 90 DAS, N_{50} showed the highest CGR (5.54 g m^{-2} day^{-1} in 2022-23), whereas N_R, had the lowest (4.18 g m^{-2} day^{-1} in 2022-23). The results reflect that though the conventional system has better growth performance; the consistency in crop growth and stability is higher under CA system (25) with crop intensification and effective nutrient management (26).

Relative growth rate

It was found that (Fig. 3A-B) at 30 DAS, CAI system recorded the highest RGR (43.13 mg g^{-1} day^{-1} in 2022-23), followed by CAS system (43.02 mg g^{-1} day^{-1} in 2022-23) and at 60 DAS, the highest

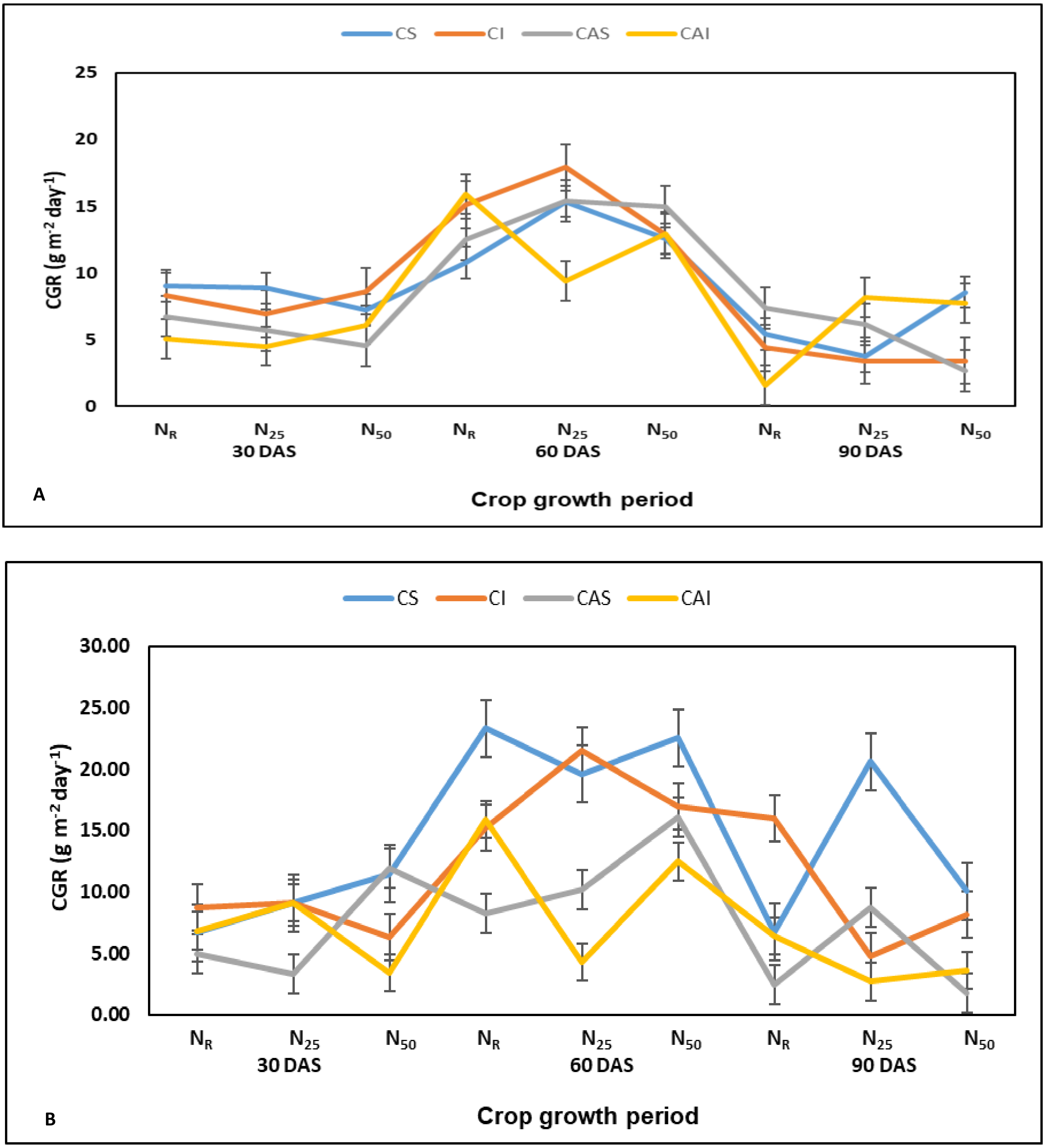


Fig. 2. CGR of rice at different dates of sowing: (**A**) 2022–23; (**B**) 2023–24.

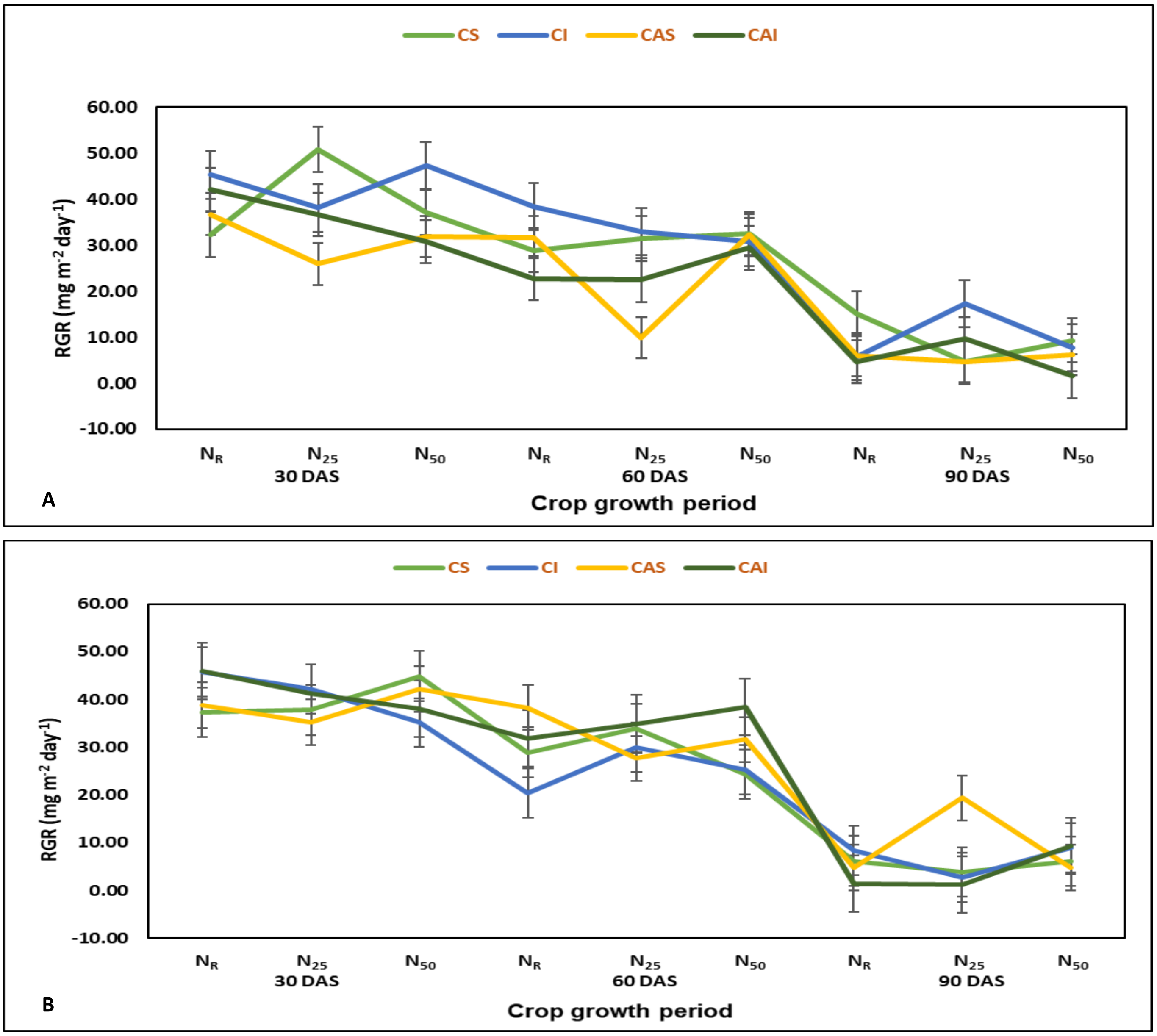


Fig. 3. RGR of rice at different dates of sowing: (**A**) 2022-23; (**B**) 2023-24.

Table 3. Effect of production system (PS) and nutrient management (N) practices over plant growth parameters of maize

Treatment	Plant height at harvest (cm)		LAI (at 90 DAS)		DMA (g m^{-2})	
	2022–23	2023–24	2022–23	2023–24	2022–23	2023–24
			PS			
Conv.+ Sole crop (CSC)	183.63	169.99	4.33	4.56	1410.11	1480.72
Conv.+ Intercrop (CIC)	189.01	190.56	4.48	4.43	1505.00	1633.85
CA + Sole crop (CASC)	189.46	193.56	4.57	4.35	1190.78	1432.34
CA + Intercrop (CAIC)	182.41	188.23	4.79	4.68	1217.22	1500.91
SE(m) ±	6.39	6.39	0.26	0.21	92.05	88.61
CD (p=0.05)	NS	NS	NS	NS	NS	NS
			N			
N_R	191.65	200.99	4.77	4.47	1425.08	1507.06
N_{25}	184.68	184.00	4.43	4.80	1374.92	1519.08
N_{50}	182.05	171.76	4.42	4.24	1192.33	1509.72
SE(m) ±	7.40	7.40	0.11	0.15	54.59	54.98
CD (p=0.05)	21.60	21.60	0.31	NS	159.33	NS
			Interaction (CD (p=0.05))			
PS*N	NS	NS	NS	NS	NS	NS
N*PS	NS	NS	NS	NS	NS	NS

Conv: Conventional; **CA**: Conservation agriculture; **N_R**: RDF; **N_{25}**: 25 % Nitrogen substitution with FYM; **N_{50}**: 50 % Nitrogen substitution with FYM.

RGR was recorded in CAS (36.78 mg g^{-1} day^{-1} in 2022-23) (27, 28). The CGR was initially low under CA system and increased during 60-90 DAS and again decreased at maturity, the other treatments also show the same trend (29). Nutrient management practices show similar trend at different growth stages (30).

Maize

The plant growth parameters of maize; plant height at harvest, DMA and LAI (Table 3) varied across production systems and nutrient management practices over two consecutive years (2022-23 and 2023-24).

Plant height at harvest

The plant height of maize at harvest shows that there was no significant difference during both years of experiment. N_R resulted in the tallest plants in 2022-23 (191.65 cm), while N_{25} produced plants with the second highest height (184.68 cm), though N_{50} performed similarly at 182.05 cm. This shows that the production systems almost produced equal plant height which may be due to 30 % residue cover under CA system (31) allowing a better root growth and shoot growth which was at par with conventional system (32).

Leaf area index

The LAI of maize at 90 DAS reflects that CAI had the highest LAI in both years (2022-23: 4.79, 2023-24: 4.68). Under nutrient management systems, N_R treatment resulted in the highest (4.77) LAI in 2022-23 however N_{25} achieved the highest (4.80) in 2023-24.

The LAI was higher in CA based system and specifically in intercrop plots showing that intercropping has positive effect on leaf area as well as DMA (33).

Dry matter accumulation

The DMA (g m^{-2}) of maize at harvest showed that the CIC

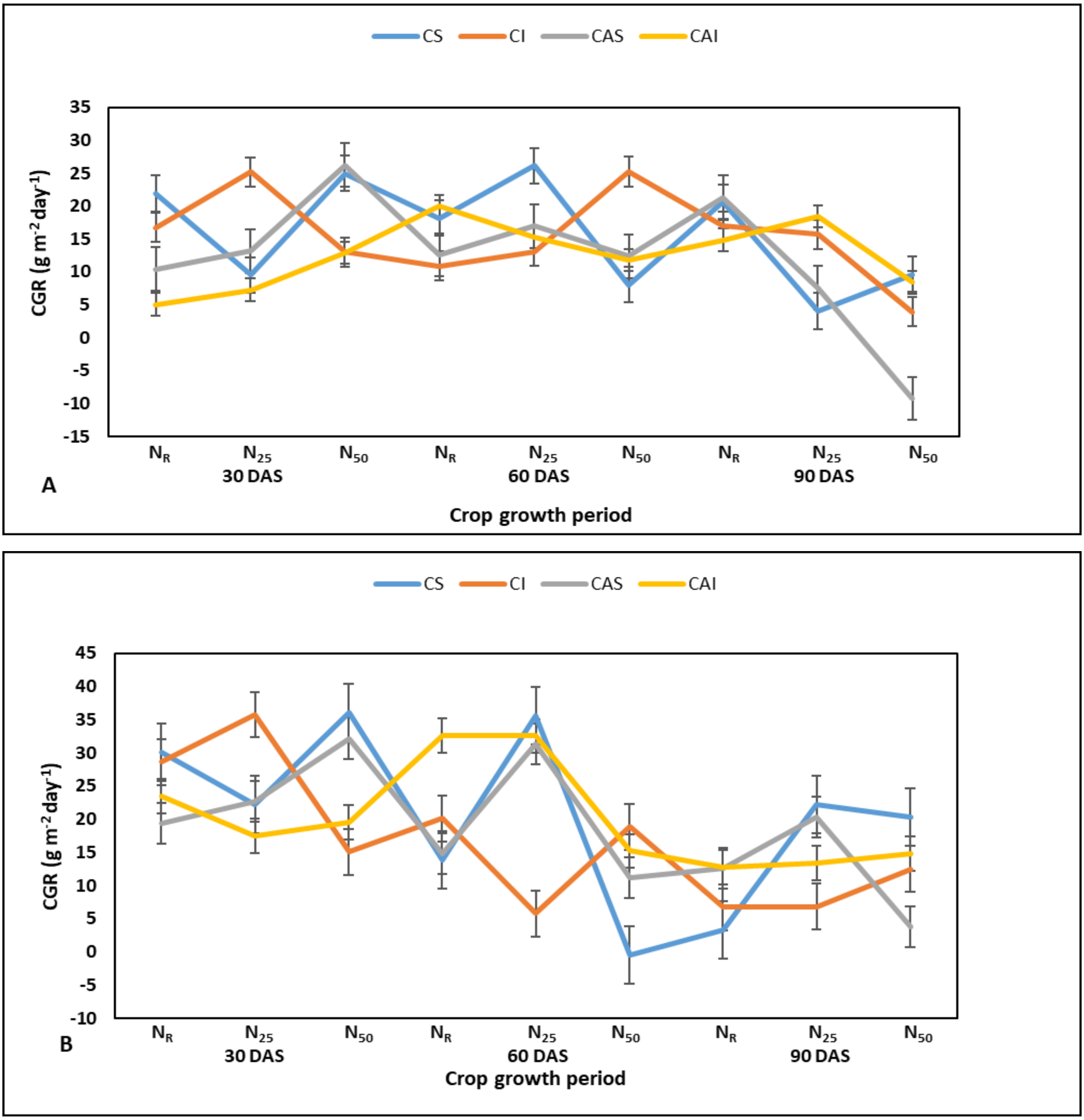


Fig. 4. CGR of maize at different dates of sowing: (**A**) 2022-23; (**B**) 2023-24.

treatment remained superior, with 1505.00 g m^{-2} in 2022-23 and 1633.85 g m^{-2} in 2023-24, reflecting its higher dry matter production over the growing season among the production systems. When maize is grown under dry season conditions, dry matter partitioning and photosynthetic assimilation are quite dependent on the presence of soil moisture (34), soil and plant microclimatic condition as well as penetration of solar radiation within the plant canopy (35). It is essential to comprehend the temporal dynamics of sole cropped and intercropped maize growth and dry matter production under various agro climatic and cultural circumstances in order to develop crop models and maximize resources for improved crop output (36).

Crop growth rate

The CGR (Fig. 4A-B) at 30 DAS, 60 DAS and 90 DAS indicated that that the highest crop growth rate was attained at 60 DAS, irrespective of the treatments. Among the nutrient management treatments, the N_{50} exhibited CGR 19.29 g m^{-2} day^{-1} in 2022-23 at 30 DAS and 25.71 g m^{-2} day^{-1} in 2023–24 at 60 DAS, which was higher than N_R and N_{25} indicating good nutrient availability and utilization for growth at early and mid-stages. Conservation agricultural practices combining minimal or no-tillage with adequate soil cover and crop diversification have emerged as an alternative practice for environmental and agricultural sustainability (37).

Relative growth rate

The RGR (Fig. 5A-B) at 30 DAS, 60 DAS and 90 DAS was evaluated to determine how different production systems and nutrient management practices affect maize growth. CSC recorded the highest RGR in 2023-24 (94.01 mg g^{-1} day^{-1}), indicating fast early growth compared to the other treatments (38, 39).

Conclusion

RM cropping system is going to play a vital role in maintaining the food security under the changing climatic conditions. Among conventional and CA based systems, the conventional system performed better in all growth attributes, but the difference was not so significant. The resource conservation techniques like

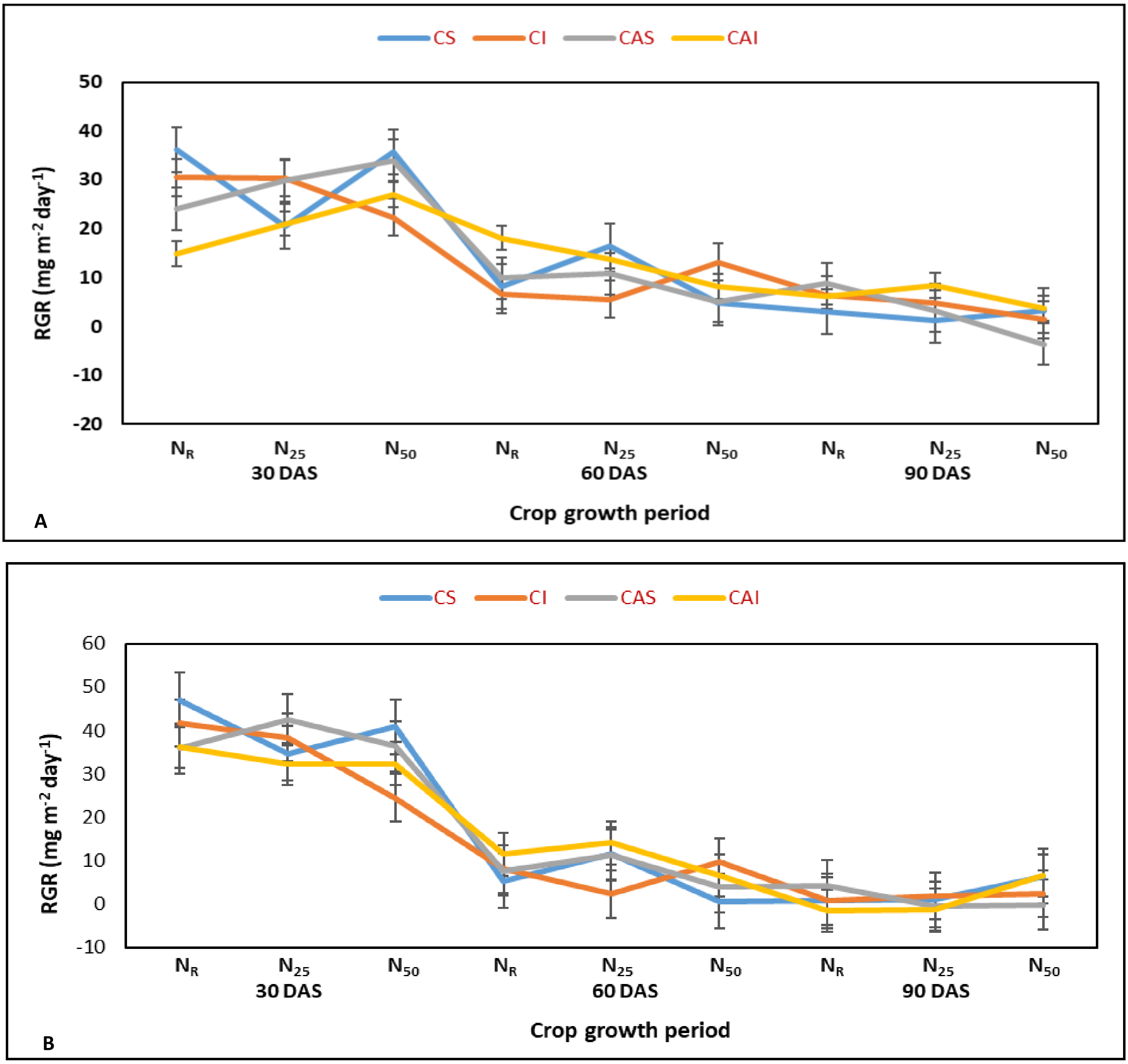


Fig. 5. RGR of maize at different dates of sowing: (**A**) 2022-23; (**B**) 2023-24.

residue retention and ZT based production system can be taken as suitable options in maintaining the crop growth and system stability in the long run when integrated with proper nutrient management techniques. In future, research on site specific nutrient management and alternate conventional with CA practices are required to maintain the crop performance and stability under different crop ecology.

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Authors' contributions

BT conceptualized and prepared the first draft of the manuscript, carried out the experiments and analysed the data. NCS conceptualized the study, curated the data, supervised the work, validated the results and contributed to the writing and formatting of the original draft. BBP conceptualized and visualized the study, administered the project operations, supervised the work, validated the results and contributed to the writing and formatting of the original draft. All authors read and approved the final 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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