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EFFECT OF DIVERSE CROP PRODUCTION SYSTEMS ON THE GROWTH PERFORMANCE OF SOYBEAN-BASED CROPPING SYSTEMS

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ABSTRACT

A field study was conducted to evaluate the effect of diverse crop production systems on the growth and yield performance of soybean-based cropping systems, focusing on three major management practices: organic farming (OF), natural farming (NF), and integrated crop management (ICM). The experiment was laid out in a randomized block design and replicated over two consecutive years. Key growth parameters of soybean and subsequent *Rabi* crops (wheat and maize) were recorded at various developmental stages, including plant population, plant height, number of leaves per plant, leaf area, leaf area index (LAI), plant dry weight, crop growth rate (CGR) and relative growth rate (RGR). The results revealed that ICM consistently supported superior vegetative growth and productivity, followed by OF and NF. In soybean, ICM achieved the highest mean plant dry weight (36.48 g plant⁻¹) and seed yield (1783.62 kg ha⁻¹), followed by OF (32.71 g; 1548.23 kg ha⁻¹), while NF recorded the lowest values (28.96 g; 1275.44 kg ha⁻¹). Similar trends were observed in wheat (ICM: 41.83 g, 2546.79 kg ha⁻¹; OF: 35.67 g, 1779.97 kg ha⁻¹; NF: 30.29 g, 1322.05 kg ha⁻¹) and maize (ICM: 51.74 g, 4155.68 kg ha⁻¹; OF: 45.32 g, 3740.21 kg ha⁻¹; NF: 38.19 g, 3115.35 kg ha⁻¹). Although, early growth parameters such as CGR and RGR showed minimal variation among treatments, cumulative dry matter accumulation and seed yield were significantly enhanced under ICM. The study concludes that integrated crop management offers a balanced and effective strategy to maximize growth and yield in soybean-based cropping systems by integrating the strengths of organic and conventional practices for improved resource-use efficiency and sustainability.

Key words : Soybean-based cropping system, Integrated crop management (ICM), Organic farming (OF), Natural farming (NF) and Growth parameters.

Introduction

Soybean (*Glycine max* L.) is a vital leguminous crop valued for its high-quality protein and oil content, contributing significantly to food, feed, and industrial sectors. In India, soybean-based cropping systems, particularly soybean-wheat and soybean-maize sequences, are widely practiced due to their economic viability and soil fertility benefits through biological nitrogen fixation (Sharma *et al.*, 2020). However, the growth and productivity of soybean are significantly influenced by the crop production systems adopted, which govern

nutrient dynamics, weed competition, and resource-use efficiency (Kumar *et al.*, 2019).

The growing concerns regarding soil health degradation, environmental pollution, and high input costs associated with conventional agriculture have prompted a shift towards more sustainable farming approaches. In this context, organic farming, natural farming and integrated crop management (ICM) have gained prominence. These systems differ in their input use strategies and ecological footprint, which directly or indirectly affect crop growth and development (Ramesh

et al., 2010; Meena *et al.*, 2022).

Organic farming emphasizes the use of composts, farmyard manure, green manures, and biofertilizers while avoiding synthetic chemicals. Studies have shown that organic practices improve soil structure, microbial activity, and moisture retention, all of which contribute to enhanced early crop growth (Panneerselvam *et al.*, 2013). Natural farming, especially the Zero Budget Natural Farming (ZBNF) model promoted in India, relies on the application of locally available materials such as Jeevamrut, Beejamrut and mulching, aimed at minimizing external inputs and enhancing native soil biology (Palekar, 2016; Kumar and Gautam, 2021).

Integrated crop management (ICM), on the other hand, combines the best practices from both conventional and ecological farming, optimizing input use efficiency while maintaining sustainability. Research indicates that ICM significantly improves nutrient uptake, weed suppression, and overall crop vigour when compared to single-approach systems (Das *et al.*, 2018; Singh *et al.*, 2021).

Despite these advancements, limited comprehensive studies are available comparing the growth responses of soybean-based cropping systems under these diverse production practices. Understanding the impact of these systems on plant height, leaf area, dry matter accumulation, and growth rates is crucial for selecting the most effective and sustainable strategy for different agro-ecological regions.

Therefore, this study aims to evaluate and compare the effect of organic, natural and integrated crop production systems on the growth performance of soybean-based cropping systems. The results will contribute valuable insights into sustainable agricultural intensification and resource-conserving practices suitable for modern farming.

Materials and Methods

A field experiment was conducted during the *Kharif*–*Rabi* seasons of 2023–24 and 2024–25 at the Instructional-cum-Research Farm, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh. Geographically located at 21°16' N latitude, 81°36' E longitude, and 298 meters above mean sea level, Raipur falls under the Eastern Plateau and Hills Zone of the tropical agro-climatic regions of India. The region experiences a mean annual rainfall of 1326 mm, predominantly during June to September, with temperatures ranging from 6°C in December to 46°C in May. The experimental soil was classified as clay loam (Kanhar - *Vertisol*), neutral in reaction, with low available nitrogen and phosphorus but

high potassium content. Composite soil samples from 0–30 cm depth was analysed for their physico-chemical properties.

The experiment was laid out in a randomized block design (RBD) with six replications during the *Kharif* seasons of 2023 and 2024, incorporating three crop management practices: natural farming (NF), organic farming (OF) and integrated crop management (ICM). During the *Rabi* seasons of 2023–24 and 2024–25, a split-plot design with three replications was used, with the same three crop management practices as main plots and two crops—wheat and maize—as sub-plot treatments. Due to differences in crop growth and yield, data for wheat and maize were analysed separately. Natural farming (T_1) involved seed treatment with Beejamri, foliar application of Jeevamrit, hand weeding, mulching, and plant protection using Agniashtra, Bramhasstra, and Neemashttra. Organic farming (T_2) included seed inoculation with bio-agents, application of farmyard manure (FYM) and rock phosphate, hand weeding, and botanical and microbial pest control. Integrated crop management (T_3) combined seed treatment with fungicides, insecticides, and biofertilizers, integrated nutrient management using 50% recommended dose of fertilizers (RDF) and 50% organic sources, herbicide application followed by hand weeding, and both chemical and biological plant protection measures.

Results and Discussion

Growth attributes of Soybean (*Kharif* 2023 & 2024)

The data on soybean plant population at 25 days after sowing (DAS) and at harvest (Table 1) revealed no significant differences among the three agricultural management practices natural farming (NF), organic farming (OF) and integrated crop management (ICM). Across all treatments and both years, the plant population remained uniform, averaging around 18 plants m^{-2} , ranging between 17 to 19 plants m^{-2} , primarily due to manual and uniform seeding (Verma *et al.*, 2019). In contrast, plant height (Table 1) was significantly influenced by the treatments at all growth stages (25, 50, 75 DAS and harvest). Plant height increased progressively with crop age and was higher in the second year. ICM consistently recorded the tallest plants across all stages, followed by OF and NF. This could be attributed to the balanced nutrient supply and more effective pest control under ICM, which combines organic and inorganic inputs to support better growth conditions (Singh *et al.*, 2021; Meena *et al.*, 2020).

Similarly, the number of trifoliolate leaves plant⁻¹ (Table 2) showed no significant variation at 25 DAS but exhibited

Table 1 : Effect of organic farming (OF), natural farming (NF), and integrated crop management (ICM) practices on soybean plant population and plant height at different growth stages.

Treatments	Plant population (no. row length m ²)						Plant height (cm)												
	25 DAS			At harvest			25 DAS			50 DAS			75 DAS			At harvest			
	2023	2024	Mean	2023	2024	Mean	2023	2024	Mean	2023	2024	Mean	2023	2024	Mean	2023	2024	Mean	
OF	17.4	17.9	17.7	17.2	17.6	17.4	17.2	19.21	21.23	20.25	42.34	43.88	43.10	52.37	54.76	51.08	62.28	63.85	62.98
NF	17.3	17.6	17.4	17.1	17.4	17.2	18.41	20.65	19.55	41.22	43.23	42.25	51.26	53.7	49.98	61.48	62.55	62.01	
ICM	18.8	19.2	19.0	18.5	18.8	18.6	22.38	23.11	22.76	48.92	50.75	49.86	61.75	64.68	60.25	67.98	72.60	70.28	
SEm±	0.51	0.64	0.98	0.42	0.47	0.50	0.42	0.42	0.25	0.25	0.80	1.21	0.92	1.57	0.73	0.82	1.36	1.37	0.86
CD (P=0.05)	NS	NS	NS	NS	NS	NS	1.35	1.37	0.80	0.80	2.57	3.88	2.94	5.01	2.33	2.63	4.36	4.38	2.77

significant differences at 50 DAS, 75 DAS and harvest. ICM consistently produced the highest number of trifoliolate leaves at all stages, followed by OF and NF. At 50 DAS, ICM recorded a mean of 8.59 leaves plant⁻¹, compared to 6.93 under OF and 6.53 under NF. At 75 DAS, the mean leaf count was 12.62 under ICM, 11.58 under OF, and 10.62 under NF. By harvest, leaf numbers declined due to natural senescence, but ICM still maintained the highest count (7.07), followed by OF (6.11) and NF (5.48). The superior performance of ICM can be attributed to timely nutrient availability, better soil microbial activity, and effective integration of organic and inorganic practices (Choudhary & Suri, 2017; Kumar *et al.*, 2020; Ramesh *et al.*, 2019). In contrast, lower leaf development in NF treatments may be due to the slower nutrient release from inputs like Jeevamritha, which may not meet the crop's immediate nutrient demand during peak vegetative stages (Patel and Meena, 2018; Ghosh *et al.*, 2016).

The number of primary branches plant⁻¹ (Table 3) in soybean was significantly influenced by natural farming (NF), organic farming (OF) and integrated crop management (ICM) across all observed growth stages 25, 50, 75 DAS and at harvest. At 25 DAS, ICM recorded the highest number of branches (mean 3.74), followed by OF (2.71) and NF (2.58). The improved branching under ICM is attributed to the balanced fertilization, better soil structure, and active microbial environment promoted by integrated approaches (Sharma *et al.*, 2020; Kumar *et al.*, 2021; Yadav *et al.*, 2019). This trend continued through 50 DAS, where ICM maintained its lead (mean 6.68), while OF (5.37) and NF (5.28) showed lower values. The limited nutrient release from jeevamrit and other bio-inputs in NF may not meet the crop's demand during high-growth phases, resulting in reduced branching (Patel and Meena, 2018; Ghosh *et al.*, 2016). At 75 DAS, ICM further extended its advantage (7.76 branches plant⁻¹), compared to OF (6.70) and NF (5.89). By harvest, ICM recorded the highest number of primary branches (8.53), followed by OF (7.31) and NF (6.35). The consistent superiority of ICM may be due to its ability to provide continuous nutrient supply and reduce stress through integrated pest and weed management, supporting robust vegetative growth (Joshi *et al.*, 2021; Reddy *et al.*, 2019; Singh *et al.*, 2021).

The dry weight plant⁻¹ of soybean (Table 4) was also significantly affected by the different crop management practices at all growth stages. At 25 DAS, ICM recorded the highest dry weight (mean 1.90 g plant⁻¹), followed by OF (1.46 g) and NF (1.21 g). This trend continued through 50 DAS, with ICM leading (21.63 g), followed by OF (18.66 g) and NF (18.35 g). At 75 DAS, ICM maintained

Table 2 : Influence of organic farming (OF), natural farming (NF), and integrated crop management (ICM) practices on the number of trifoliate leaves of soybean at various time intervals.

Treatments	Number of trifoliate leaves plant ⁻¹											
	25 DAS			50 DAS			75 DAS			At harvest		
	2023	2024	Mean	2023	2024	Mean	2023	2024	Mean	2023	2024	Mean
OF	3.46	3.81	3.64	6.50	7.36	6.93	11.41	11.75	11.58	6.06	6.16	6.11
NF	3.43	3.73	3.58	6.11	6.95	6.53	10.50	10.73	10.62	5.41	5.55	5.48
ICM	3.90	4.05	3.98	7.61	9.56	8.59	12.48	12.75	12.62	6.96	7.18	7.07
SEm±	0.24	0.12	0.15	0.22	0.22	0.17	0.07	0.18	0.10	0.12	0.08	0.05
CD (P=0.05)	NS	NS	NS	0.70	0.70	0.54	0.23	0.57	0.33	0.38	0.27	0.16

Table 3 : Influence of organic farming (OF), natural farming (NF), and integrated crop management (ICM) practices on the number of primary branches of soybean at various time intervals.

Treatments	Number of primary branches plant ⁻¹											
	25 DAS			50 DAS			75 DAS			At harvest		
	2023	2024	Mean	2023	2024	Mean	2023	2024	Mean	2023	2024	Mean
OF	2.63	2.78	2.71	5.26	5.48	5.37	6.58	6.81	6.70	7.26	7.36	7.31
NF	2.50	2.65	2.58	5.16	5.40	5.28	5.80	5.98	5.89	6.25	6.45	6.35
ICM	3.66	3.81	3.74	6.60	6.76	6.68	7.63	7.88	7.76	8.43	8.63	8.53
SEm±	0.09	0.03	0.05	0.27	0.36	0.21	0.22	0.25	0.20	0.12	0.16	0.12
CD (P=0.05)	0.30	0.13	0.17	0.87	1.17	0.68	0.70	0.80	0.64	0.38	0.45	0.38

Table 4 : Influence of organic farming (OF), natural farming (NF), and integrated crop management (ICM) practices on the dry weight of soybean at various time intervals.

Treatments	Dry weight (g plant ⁻¹)											
	25 DAS			50 DAS			75 DAS			At harvest		
	2023	2024	Mean	2023	2024	Mean	2023	2024	Mean	2023	2024	Mean
OF	1.36	1.56	1.46	17.91	19.41	18.66	39.52	42.61	41.06	46.16	48.49	47.33
NF	1.13	1.28	1.21	17.65	19.05	18.35	38.86	40.47	39.66	43.76	45.93	44.84
ICM	1.76	2.01	1.90	20.73	22.51	21.63	46.88	48.21	47.54	51.75	53.92	52.83
SEm±	0.16	0.17	0.16	0.41	0.62	0.37	0.75	0.86	0.63	0.47	1.07	0.57
CD (P=0.05)	0.51	0.55	0.52	1.31	1.98	1.20	2.41	2.77	2.02	1.51	3.42	1.84

a significant advantage (47.54 g), while OF (41.06 g) and NF (39.66 g) showed comparatively lower biomass accumulation. At harvest, ICM again recorded the highest dry weight plant⁻¹ (52.83 g), with OF and NF showing 47.33 g and 44.84 g, respectively. The superior dry matter accumulation under ICM across all stages is attributed to timely and efficient nutrient availability, improved microbial activity, and optimal plant health, all of which promote higher photosynthesis and biomass production (Meena *et al.*, 2020; Choudhary and Suri, 2017; Ramesh *et al.*, 2019). The reduced biomass under NF reflects limitations in immediate nutrient availability from bio-stimulants like jeevamrit, especially during peak crop demand periods (Ghosh *et al.*, 2016; Patel and Meena, 2018).

The leaf area of soybean (Table 5) was significantly

influenced by different management practices natural farming (NF), organic farming (OF), and integrated crop management (ICM) at all growth stages (25, 50, 75 DAS, and at harvest) across both years. Leaf area increased progressively up to 75 DAS and declined thereafter due to natural senescence. ICM consistently recorded the highest leaf area at all stages, with mean values of 223.66 cm² at 25 DAS, 810.56 cm² at 50 DAS and 1246.33 cm² at 75 DAS, reflecting better nutrient availability, water retention, and microbial activity (Sharma *et al.*, 2020; Meena *et al.*, 2021). OF performed moderately, while NF showed the lowest leaf area, likely due to slower nutrient mineralization from bio-inputs like Jeevamrit and compost (Patel and Meena, 2018; Ghosh *et al.*, 2016). Even at harvest, where leaf senescence was evident, ICM maintained superiority in leaf area, followed by OF and NF.

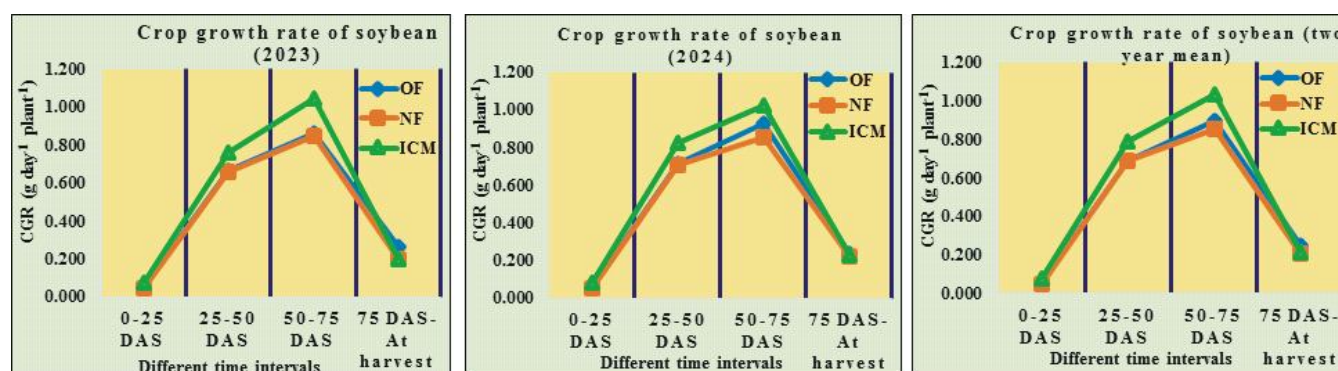


Fig. 1 : Crop growth rate at various stages of soybean as influenced by organic farming (OF), natural farming (NF), and integrated crop management (ICM) practices.

Similarly, the leaf area index (LAI) (Table 6) was significantly affected by the crop management strategies across all stages. ICM recorded the highest LAI values at 25 DAS (1.02), 50 DAS (3.61), 75 DAS (5.54), and at harvest, due to efficient nutrient cycling and enhanced canopy development (Kumar *et al.*, 2021; Reddy *et al.*, 2019). In contrast, NF treatments exhibited consistently lower LAI values due to insufficient nitrogen supply and limited nutrient release, which adversely affected leaf expansion and photosynthetic capacity (Patel *et al.*, 2020; Joshi *et al.*, 2021). The optimal LAI range for soybean yield potential (3.5–5.5) was well-achieved under ICM during the peak vegetative stage, while OF hovered around the lower end of the optimal range and NF remained below it.

In contrast to leaf area and LAI, the crop growth rate (CGR) showed no statistically significant variation among treatments during all the observed intervals 0–25 DAS, 25–50 DAS, 50–75 DAS, and 75 DAS to harvest (Fig. 1). The uniformity in CGR across treatments can be attributed to inherent growth patterns in soybean during early vegetative development, with minimal influence of nutrient regimes in initial stages (Singh *et al.*, 2021). Similarly, relative growth rate (RGR) also remained unaffected by management practices throughout the crop cycle (Fig. 2). The physiological stability in RGR suggests that soybean maintains efficient biomass production regardless of external management variations, likely due to its adaptive metabolic flexibility (Kumar *et al.*, 2020).

The number and dry weight of nodules plant^{-1} in soybean were significantly influenced by different crop management systems natural farming (NF), organic farming (OF), and integrated crop management (ICM) at both 25 and 50 days after sowing (DAS), as shown in Table 7. At 25 DAS, ICM consistently recorded the highest number of nodules (mean 22.58 nodules plant^{-1}), followed closely by OF (20.60), while NF showed the lowest values (14.66). This trend was further amplified

at 50 DAS, with ICM producing 162.75 nodules plant^{-1} on average, followed by OF (158.51) and NF (141.18). The superior nodulation under ICM may be attributed to the combined application of organic and inorganic inputs, which improve soil fertility, microbial population, and nutrient availability key factors for effective rhizobium colonization and biological nitrogen fixation (Sharma *et al.*, 2020; Patel and Verma, 2019). Studies suggest that properly nodulated soybean roots typically bear 25–150 nodules, which continue developing until flowering and pod formation stages (Lofton and Arnall, 2017; Penn State Extension, 2023).

The dry weight of nodules followed a similar pattern, with ICM treatments outperforming others at both stages. At 25 DAS, ICM recorded the highest dry weight (mean 159.90 mg plant^{-1}), followed by OF (153.30 mg) and NF (140.02 mg). At 50 DAS, ICM again led with a mean nodule dry weight of 874.93 mg plant^{-1} , while OF and NF recorded 832.96 mg and 774.63 mg, respectively. The increase in nodule biomass under ICM likely reflects enhanced plant vigour, root activity, and nodulation efficiency, promoted by balanced nutrient regimes and improved soil microbial environments (Kumar *et al.*, 2020; Meena and Singh, 2018).

The seed yield of soybean was significantly influenced by the crop management practices natural farming (NF), organic farming (OF), and integrated crop management (ICM) across both study years and on a pooled mean basis, as shown in Table 7. Integrated crop management consistently recorded the highest seed yield, with values of 2152.70 kg ha^{-1} in the first year, 2578.70 kg ha^{-1} in the second year, and a pooled mean of 2365.70 kg ha^{-1} . This superior performance under ICM can be attributed to a balanced and timely supply of nutrients, effective weed and pest control, and enhanced soil health, which collectively contributed to improved plant growth, efficient nutrient uptake, and greater reproductive output (Patel *et al.*, 2021; Meena *et al.*, 2020). Organic farming

Table 5 : Influence of organic farming (OF), natural farming (NF), and integrated crop management (ICM) practices on the leaf area of soybean at various time intervals.

Treatments	Leaf area (cm ² plant ⁻¹)											
	25 DAS			50 DAS			75 DAS			At harvest		
	2023	2024	Mean	2023	2024	Mean	2023	2024	Mean	2023	2024	Mean
OF	176.63	183.30	179.97	707.40	747.06	727.23	1093.90	1118.90	1106.40	563.50	583.50	573.50
NF	160.73	167.40	164.07	650.35	683.68	667.02	1021.83	1053.50	1037.67	534.16	550.83	542.50
ICM	223.66	242.50	233.08	785.56	835.56	810.56	1226.33	1266.33	1246.33	659.83	684.83	672.33
SEm±	3.93	3.66	2.62	11.95	24.10	14.24	15.77	20.66	14.85	5.28	18.08	9.57
CD (P=0.05)	12.53	11.68	8.35	38.12	76.89	45.43	50.34	65.93	47.40	16.83	57.71	30.22

Table 6 : Influence of organic farming (OF), natural farming (NF), and integrated crop management (ICM) practices on the leaf area index of soybean at various time intervals.

Treatments	Leaf area index (LAI)											
	25 DAS			50 DAS			75 DAS			At harvest		
	2023	2024	Mean	2023	2024	Mean	2023	2024	Mean	2023	2024	Mean
OF	0.80	0.82	0.81	3.15	3.32	3.24	4.87	4.97	4.92	2.50	2.58	2.54
NF	0.70	0.73	0.72	2.90	3.03	2.97	4.57	4.68	4.63	2.38	2.45	2.42
ICM	1.01	1.03	1.02	3.48	3.73	3.61	5.45	5.62	5.54	2.93	3.03	2.98
SEm±	0.018	0.018	0.016	0.056	0.102	0.059	0.071	0.094	0.073	0.021	0.078	0.045
CD (P=0.05)	0.057	0.057	0.051	0.177	0.324	0.188	0.228	0.301	0.233	0.066	0.249	0.143

recorded intermediate yields (1667.32, 2308.74 and 1988.03 kg ha⁻¹), benefiting from enhanced soil organic matter and microbial activity, though possibly limited by slower nutrient release and reduced nitrogen availability during peak demand periods. The lowest seed yield was observed under natural farming (1293.89, 1569.73, and 1431.81 kg ha⁻¹), likely due to nutrient constraints, lower biological nitrogen fixation, and restricted use of external inputs, which could hinder both vegetative and reproductive development (Singh *et al.*, 2022; Ghosh *et al.*, 2016). These findings align with previous studies emphasizing that the integration of organic and inorganic nutrient sources in ICM promotes better synchronization with crop nutrient demand and contributes to higher soybean productivity in sustainable systems (Kumar *et al.*, 2020; Yadav *et al.*, 2019).

Growth attributes of Wheat (Rabi 2023-24 & 2024-25)

The growth performance of wheat under a soybean-based cropping system was influenced by different crop management practices, including organic farming (OF), natural farming (NF), and integrated crop management (ICM). Plant population (Table 8) remained uniform across all treatments at both early (25 DAS) and harvest stages, with 18–20 plants meter⁻¹ row length, indicating good crop establishment and minimal plant loss across systems. Plant height (Table 8) showed a steady increase up to 75 DAS, with a slower rise thereafter. Wheat plants

under ICM generally attained greater height, followed by those under OF and NF. This trend may be attributed to better nutrient availability and overall crop care under ICM practices (Singh *et al.*, 2021). The number of leaves plant⁻¹ (Table 9) also increased from 25 to 75 DAS, followed by a decline due to leaf senescence by harvest. ICM-treated plots typically produced more leaves plant⁻¹, which can be linked to sustained vegetative growth and efficient resource use (Kumar *et al.*, 2019; Patel *et al.*, 2022; Rao *et al.*, 2021).

Leaf area plant⁻¹ (Table 10) increased gradually up to 75 DAS and then declined due to the drying and shedding of older leaves. ICM management promoted greater leaf area, likely due to timely nutrient application, better weed and water management and improved agronomic operations (Sharma *et al.*, 2019; Kumar and Yadav, 2020). Similarly, leaf area index (LAI) (Table 11) followed a rising trend until 75 DAS and then decreased at harvest. Higher LAI values were generally observed under ICM, supported by improved canopy development and better utilization of growth resources (Singh *et al.*, 2018; Meena *et al.*, 2020). NF plots consistently showed lower vegetative growth parameters, possibly due to limited input use and slower nutrient availability.

The accumulation of plant dry weight (Table 12) in wheat under a soybean-based cropping system varied across organic farming (OF), natural farming (NF), and integrated crop management (ICM) practices. Initially

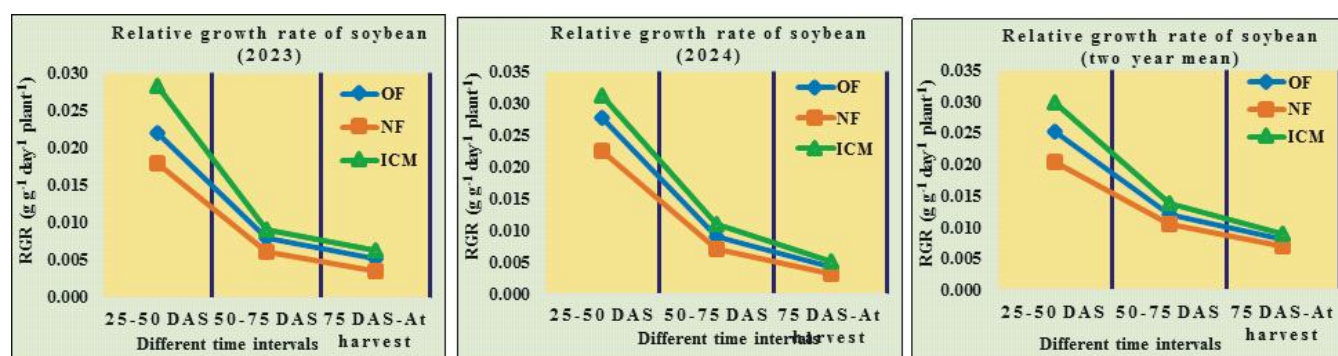


Fig. 2 : Relative growth rate at various stages of soybean as influenced by organic farming (OF), natural farming (NF), and integrated crop management (ICM) practices.

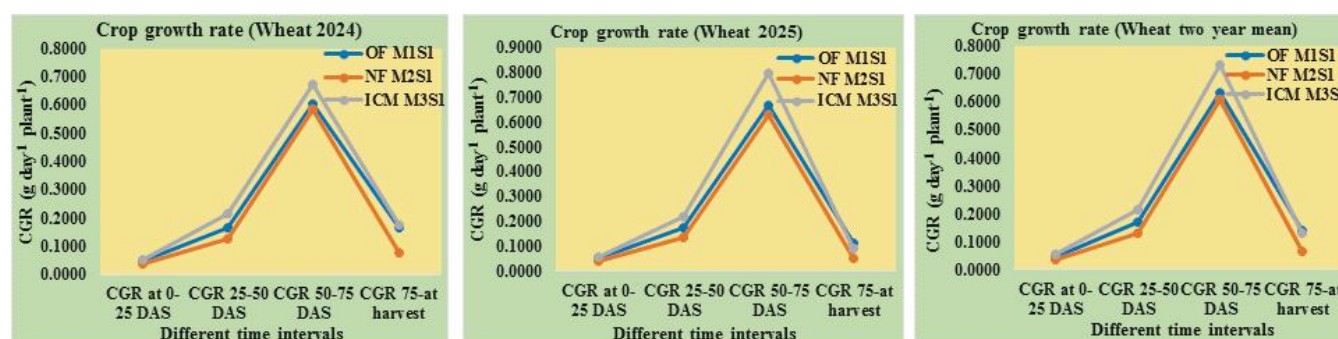


Fig. 3 : Crop growth rate at various stages of wheat under a soybean-based cropping system as influenced by organic farming (OF), natural farming (NF), and integrated crop management (ICM) practices.

(25 DAS), dry matter accumulation was gradual as plants established, but accelerated significantly by 50 DAS with increased leaf production and tillering. This phase coincided with enhanced photosynthesis due to increased leaf area, contributing to higher biomass accumulation. From 50 to 75 DAS, dry weight continued to rise as plants entered booting and flowering stages, allocating more resources to reproductive structures. By harvest, dry weight plateaued, reflecting the plant's total biomass production over its life cycle, shaped by light, temperature, water, nutrients, and genetic factors. Among the management systems, wheat grown under ICM consistently recorded higher dry matter accumulation at all growth stages, followed by OF and then NF (Singh *et al.*, 2021).

Crop growth rate (CGR) (Fig. 3) showed minimal variation across treatments at different intervals (0–25 DAS, 25–50 DAS, 50–75 DAS, and 75 DAS to harvest). This suggests that early wheat growth is predominantly driven by the crop's intrinsic growth potential rather than external inputs, as early nutrient demands are relatively low and can be met by baseline soil fertility. The impact of crop management becomes more relevant in later stages when nutrient and water demand increase, and the effectiveness of each system's practices begins to influence growth outcomes more clearly (Singh *et al.*, 2021).

Similarly, the relative growth rate (RGR) (Fig. 4) remained consistent across all treatments during the 25–50 DAS, 50–75 DAS, and 75 DAS to harvest phases. This stability suggests that wheat maintains physiological growth efficiency regardless of management system, likely due to its inherent adaptability. Mechanisms such as efficient nutrient remobilization, stable photosynthetic activity, and regulated hormonal balance may help maintain RGR across diverse production environments (Kumar *et al.*, 2020). Overall, while early growth rates (CGR and RGR) appear unaffected by management practices, ICM supports greater total biomass accumulation, indicating its long-term advantage in sustaining wheat productivity under soybean-based cropping systems.

Seed yield (Table 12) of wheat cultivated under a soybean-based cropping system was influenced by the crop management practices adopted organic farming (OF), natural farming (NF), and integrated crop management (ICM). Across both years of the study, wheat under ICM consistently recorded the highest seed yield, with values ranging from 2474.67 kg ha⁻¹ in the first year to 2618.91 kg ha⁻¹ in the second, and a mean yield of 2546.79 kg ha⁻¹. This enhanced productivity under ICM can be associated with the synergistic effects of balanced nutrient supply, timely pest and weed control, and optimized agronomic operations that together promote better crop growth and seed formation (Kumar *et al.*,

Table 7 : Number of nodules, dry weight of nodules at 25 and 50 DAS and seed yield of soybean as influenced by organic farming (OF), natural farming (NF) and integrated crop management (ICM) practices.

Treatments	Number of nodules (plant ⁻¹)					Dry weight of nodules (mg plant ⁻¹)					Seed yield (kg ha ⁻¹)				
	25 DAS					50 DAS					50 DAS				
	2023	2024	Mean	2023	2024	Mean	2023	2024	Mean	2023	2024	Mean	2023	2024	Mean
OF	18.26	22.91	20.60	153.36	161.61	157.51	150.23	156.36	153.30	824.61	841.31	832.96	1667.32	2308.74	1988.03
NF	13.08	16.25	14.66	137.46	144.85	141.18	137.73	142.31	140.02	766.88	782.38	774.63	1293.89	1569.73	1431.81
ICM	20.56	24.55	22.58	160.16	165.30	162.75	156.55	163.25	159.90	864.30	885.56	874.93	2152.70	2578.70	2365.70
SEm±	1.35	1.41	1.00	1.74	2.03	1.25	1.07	1.51	0.81	12.46	6.48	6.90	51.87	46.65	39.85
CD (P=0.05)	4.32	4.52	3.19	5.55	6.47	4.01	3.43	4.82	2.59	39.79	20.68	22.02	165.56	148.91	127.19

Table 8 : Influence of organic farming (OF), natural farming (NF), and integrated crop management (ICM) practices on wheat plant population and plant height at various growth stages under a soybean-based cropping system.

Treatments	Plant population m ⁻² row length					Plant height (cm)									
	25 DAS					At harvest					25 DAS				
	2024	2025	Mean	2024	2025	Mean	2024	2025	Mean	2024	2025	Mean	2024	2025	Mean
OF	18.68	19.08	18.88	18.58	18.92	18.75	17.56	19.84	18.70	53.82	55.51	54.67	88.49	89.47	88.98
NF	18.56	19.01	18.78	18.44	18.88	18.66	17.53	18.65	18.09	51.42	53.34	52.38	86.19	87.84	87.02
ICM	19.22	19.54	19.38	19.02	19.48	19.25	20.08	22.67	21.38	58.99	60.65	59.82	95.82	96.24	96.03

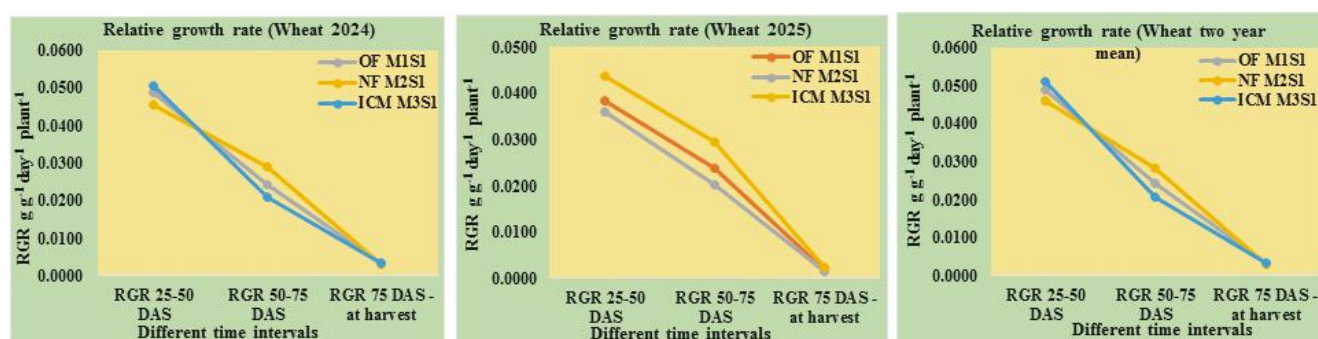


Fig. 4 : Relative growth rate at various stages of wheat under a soybean-based cropping system as influenced by organic farming (OF), natural farming (NF), and integrated crop management (ICM) practices.

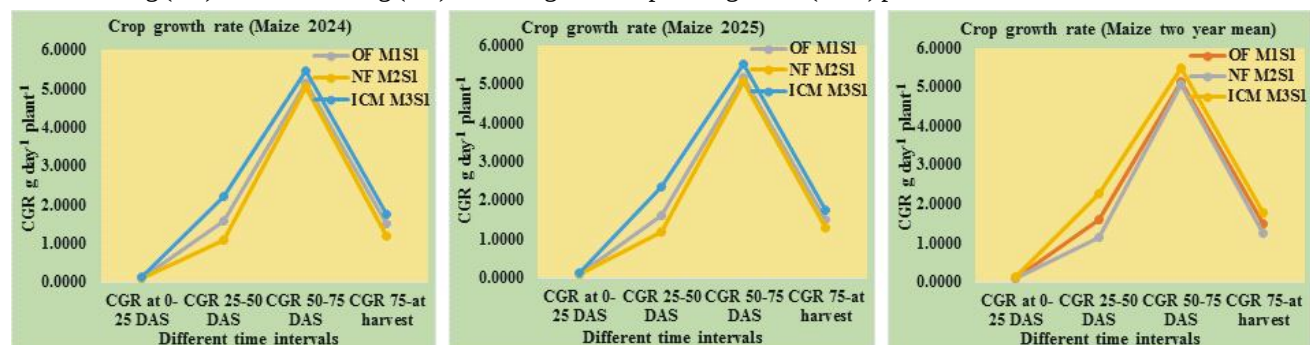


Fig. 5 : Crop growth rate at various stages of maize under a soybean-based cropping system as influenced by organic farming (OF), natural farming (NF), and integrated crop management (ICM) practices.

Table 9 : Effect of organic farming (OF), natural farming (NF), and integrated crop management (ICM) practices on the number of leaves of wheat at different time intervals under a soybean-based cropping system.

Treatments	Number of leaves plant ⁻¹											
	25 DAS			50 DAS			75 DAS			At harvest		
	2024	2025	Mean	2024	2025	Mean	2024	2025	Mean	2024	2025	Mean
OF	4.38	4.43	4.41	6.47	6.65	6.56	8.35	8.46	8.41	5.32	5.36	5.34
NF	4.35	4.39	4.37	6.35	6.34	6.35	7.40	7.48	7.44	5.18	5.19	5.18
ICM	4.61	4.72	4.67	6.80	6.96	6.88	9.35	9.43	9.39	5.58	5.64	5.61

Table 10 : Leaf area plant⁻¹ in wheat under a soybean-based cropping system at different time intervals as influenced by organic farming (OF), natural farming (NF), and integrated crop management (ICM) practices.

Treatments	Leaf area (cm ² plant ⁻¹)											
	25 DAS			50 DAS			75 DAS			At harvest		
	2024	2025	Mean	2024	2025	Mean	2024	2025	Mean	2024	2025	Mean
OF	29.59	31.54	30.57	189.48	196.25	192.87	353.27	370.14	361.70	251.70	261.51	256.61
NF	25.39	27.49	26.44	179.22	184.57	181.90	306.87	320.17	313.52	194.80	209.45	202.13
ICM	33.44	36.46	34.95	203.23	214.53	208.88	446.47	481.37	463.92	315.67	322.67	319.17

Table 11 : Leaf area index in wheat under a soybean-based cropping system at different time intervals as influenced by organic farming (OF), natural farming (NF), and integrated crop management (ICM) practices.

Treatments	Leaf area index											
	25 DAS			50 DAS			75 DAS			At harvest		
	2024	2025	Mean	2024	2025	Mean	2024	2025	Mean	2024	2025	Mean
OF	0.27	0.29	0.28	1.72	1.78	1.75	3.21	3.36	3.29	2.29	2.38	2.33
NF	0.23	0.25	0.24	1.63	1.68	1.65	2.79	2.91	2.85	1.77	1.90	1.84
ICM	0.30	0.33	0.32	1.85	1.95	1.90	4.06	4.38	4.22	2.87	2.93	2.90

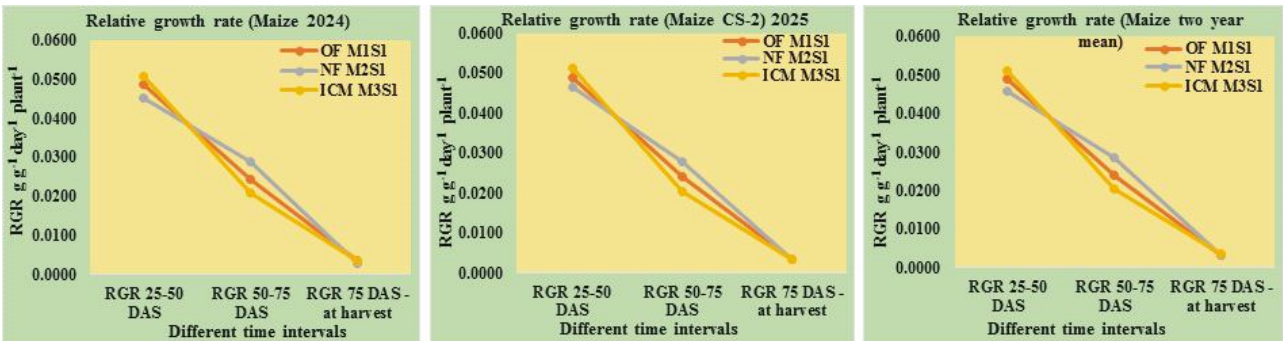


Fig. 6 : Relative growth rate at various stages of maize under a soybean-based cropping system as influenced by organic farming (OF), natural farming (NF), and integrated crop management (ICM) practices.

Table 12 : Effect of organic farming (OF), natural farming (NF), and integrated crop management (ICM) practices on the dry weight and seed yield of wheat under a soybean-based cropping system at various time intervals.

Treatments	Dry weight (g plant ⁻¹)												Seed yield (kg ha ⁻¹)		
	25 DAS			50 DAS			75 DAS			At harvest					
	2024	2025	Mean	2024	2025	Mean	2024	2025	Mean	2024	2025	Mean	2024	2025	Mean
OF	1.17	1.24	1.21	5.28	5.67	5.48	20.36	22.32	21.34	24.49	25.14	24.82	1698.54	1861.40	1779.97
NF	0.90	0.98	0.94	4.05	4.42	4.24	18.66	20.16	19.41	20.61	21.43	21.02	1261.49	1382.61	1322.05
ICM	1.37	1.49	1.43	6.68	6.93	6.81	23.54	26.84	25.19	27.91	29.12	28.52	2474.67	2618.91	2546.79

2019). Organic farming produced intermediate seed yields 1698.54 kg ha⁻¹ in the first year, 1861.40 kg ha⁻¹ in the second and a pooled mean of 1779.97 kg ha⁻¹. Although organic practices are known for improving long-term soil health and sustainability, short-term yield potential may be restricted due to slower nutrient release and limited efficacy of organic pest and disease management strategies. Natural farming recorded the lowest seed yield across the study period, with 1261.49 kg ha⁻¹ in the first year, 1382.61 kg ha⁻¹ in the second year and an average of 1322.05 kg ha⁻¹. The lower productivity under NF may be attributed to minimal external inputs and the system’s dependence on naturally available nutrients and biological processes, which may not always align with the crop’s nutritional demands during critical growth phases. Overall, integrated crop management supported superior seed yield performance in wheat, highlighting its potential to balance productivity with sustainability in soybean-based cropping systems.

Growth attributes of Wheat (Rabi 2023-24 & 2024-25)

The growth and development of maize under a soybean-based cropping system were influenced by different crop management practices organic farming (OF), natural farming (NF) and integrated crop management (ICM). Plant population (Table 13) remained similar across treatments at 25 DAS (4.5–4.9 plants m⁻¹) and declined slightly by harvest (4.4–4.8 plants m⁻¹), showing minimal treatment effect on crop establishment. Maize plant height (Table 13) increased rapidly between

25 and 75 DAS, followed by slower growth up to harvest. Across all stages, the tallest plants were consistently recorded under ICM, followed by OF, with NF showing the lowest height. This trend reflects the impact of nutrient availability and crop care, with ICM promoting vigorous growth through balanced fertilization and timely interventions (Kumar *et al.*, 2018).

The number of leaves plant⁻¹ (Table 14) also followed a similar pattern. At 75 DAS, ICM recorded the highest leaf count (mean: 16.84), followed by OF (14.63) and NF (12.79). The enhanced leaf production under ICM may be attributed to better nutrient supply, effective weed and water management and optimized agronomic practices, which together improve vegetative vigor (Patel *et al.*, 2017; Singh & Meena, 2019). The reduced leaf count under NF reflects limitations in nutrient input and physiological activity.

Leaf area plant⁻¹ (Table 15) was consistently highest under ICM at all growth stages, followed by OF and then NF. The superior leaf expansion in ICM treatments is likely due to better nutrient uptake, improved moisture retention and comprehensive crop care (Verma and Yadav, 2020). Correspondingly, the leaf area index (LAI) (Table 16) increased up to 75 DAS (3.52–4.69) and declined thereafter due to leaf senescence. Higher LAI under ICM highlights improved canopy development and greater photosynthetic efficiency, while NF’s lower LAI indicates restricted foliage growth (Sharma *et al.*, 2017; Yadav and Kumar, 2019).

Table 13 : Plant population and plant height at different time intervals of maize under soybean-based cropping system as affected by organic farming (OF), natural farming (NF) and integrated crop management (ICM) practices.

Treatments	Plant population (m ² row length)						Plant height (cm)											
	At 25 DAS			At harvest			At 25 DAS				At 50 DAS				At 75 DAS			
	2024	2025	Mean	2024	2025	Mean	2024	2025	Mean	2024	2025	Mean	2024	2025	Mean	2024	2025	Mean
OF	4.6	4.7	4.7	4.5	4.6	4.6	43.79	45.36	44.58	123.8	124.61	124.21	174.56	177.68	176.12	177.65	180.24	178.95
NF	4.5	4.6	4.6	4.4	4.5	4.5	43.09	44.27	43.68	115.67	116.78	116.23	151.65	153.24	152.45	155.06	157.46	156.26
ICM	4.8	4.9	4.9	4.7	4.8	4.8	45.81	47.64	46.73	137.47	140.38	138.93	210.04	216.47	213.26	219.49	221.16	220.33

Table 14 : Number of leaves at different time intervals of maize under soybean-based cropping system as affected by organic farming (OF), natural farming (NF), and integrated crop management (ICM) practices

Treatments	Number of leaves (plant ⁻¹)																	
	25 DAS						50 DAS						75 DAS					
	2024	2025	Mean	2024	2025	Mean	2024	2025	Mean	2024	2025	Mean	2024	2025	Mean	2024	2025	Mean
OF	5.62	5.65	5.64	9.60	9.64	9.62	14.59	14.68	14.63	12.72	12.86	12.79	16.75	16.92	16.84	11.54	11.40	11.47
NF	5.57	5.59	5.58	9.30	9.36	9.33	12.72	12.86	12.79	16.75	16.92	16.84	12.72	12.86	12.79	10.58	10.50	10.54
ICM	5.86	5.91	5.89	9.72	9.80	9.76	16.75	16.92	16.84	12.72	12.86	12.79	16.75	16.92	16.84	12.39	12.29	12.34

Table 17 : Plant dry weight at different time intervals of maize under soybean-based cropping system as affected by organic farming (OF), natural farming (NF), and integrated crop management (ICM) practices.

Treatments	Dry weight (g plant ⁻¹)												Seed yield (kg ha ⁻¹)				
	25 DAS			50 DAS			75 DAS			At harvest							
	2024	2025	Mean	2024	2025	Mean	2024	2025	Mean	2024	2025	Mean	2024	2025	Mean		
OF	2.54	2.58	2.56	42.14	43.16	42.65	170.34	172.21	171.28	207.66	209.56	208.61	3626.24	3854.18	3740.21		
NF	2.16	2.18	2.17	29.46	31.54	30.50	155.77	158.12	156.95	185.14	190.48	187.81	3045.20	3185.49	3115.35		
ICM	3.17	3.20	3.19	58.55	61.47	60.01	194.74	199.46	197.10	238.45	243.57	241.01	4015.51	4295.84	4155.68		

Dry matter accumulation (Table 17) in maize increased steadily from 25 DAS to 75 DAS and plateaued at maturity. ICM recorded the highest dry weight at all stages, followed by OF and NF. The superior biomass accumulation under ICM is linked to optimal nutrient management and early vigor from integrated input use (Kumar *et al.*, 2018). In contrast, NF exhibited the lowest biomass due to limited nutrient supply and minimal external inputs.

Crop growth rate (CGR) (Fig. 5) and relative growth rate (RGR) (Fig. 6) showed no substantial differences across treatments during the growth periods (0–25, 25–50, 50–75 DAS, and harvest). This suggests that early maize growth is more dependent on genetic potential than management practices, although input differences may become more evident in later stages (Singh *et al.*, 2021; Kumar *et al.*, 2020). Despite similar physiological growth rates, ICM supported greater biomass accumulation, reinforcing its advantage in achieving better vegetative development and potential yield.

Seed yield of maize (Table 17) under a soybean-based cropping system varied notably with the type of crop management practice. Integrated crop management (ICM) consistently produced the highest seed yield, with values of 4015.51 kg ha⁻¹ in the first year, 4295.84 kg ha⁻¹ in the second, and a mean of 4155.68 kg ha⁻¹. This superior performance is attributed to balanced nutrient input, improved soil fertility, and efficient agronomic practices that enhance overall crop productivity (Singh *et al.*, 2020). Organic farming (OF) resulted in intermediate yields (mean: 3740.21 kg ha⁻¹), reflecting its benefits in sustaining soil health, though nutrient availability and pest management may be less efficient compared to ICM. Natural farming (NF) recorded the lowest yields (mean: 3115.35 kg ha⁻¹), likely due to minimal external input use and lower nutrient availability during critical growth stages. These findings highlight the yield advantage of ICM and its ability to support higher maize productivity through integrated and resource-efficient crop management (Yadav *et al.*, 2021).

Conclusion

The study on the effect of diverse crop management practices organic farming (OF), natural farming (NF), and integrated crop management (ICM) on the growth and productivity of soybean-based cropping systems revealed significant advantages associated with integrated approaches. ICM consistently outperformed both OF and NF across key growth parameters such as plant height, number of leaves, leaf area, leaf area index (LAI), plant dry weight, and final seed yield in soybean,

wheat, and maize. While organic farming showed moderate improvements due to enhanced soil health and ecological balance, natural farming often lagged behind, likely due to limited external inputs and slower nutrient release. Plant establishment remained uniform across all systems, indicating that early germination and survival were not majorly affected by the management type. However, vegetative and reproductive development showed clear advantages under ICM, attributed to balanced nutrient availability, better pest and weed control, and optimized agronomic operations. Dry matter accumulation and yield trends further confirmed ICM's capacity to support higher biomass and economic output. Although crop growth rate (CGR) and relative growth rate (RGR) showed minimal variation across treatments during early stages, the cumulative benefits of ICM became evident in later growth phases and final yields. Overall, the findings underscore that ICM provides a productive and sustainable crop management strategy in soybean-based systems by integrating organic and inorganic inputs for improved resource-use efficiency, enhanced vegetative growth, and greater yield potential. Organic farming remains a viable option for long-term soil health, while natural farming, though environmentally benign, may require further refinement to achieve competitive productivity levels.

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