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Comparative assessment of integrated crop management and natural farming on growth, yield components, dry matter production and nutrient dynamics of paddy (*Oryza sativa* L.)

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Abstract

A field experiment was conducted during *Kharif* 2021 to evaluate the performance of paddy (*Oryza sativa* L.) under two farming systems: Integrated Crop Management (ICM) and Natural Farming (NF). Large plot was selected for each system and assessed for plant height, number of tillers per hill, panicle length, number of grains per panicle, number of panicles per hill, dry matter production, grain and straw yield and major nutrient (N, P, K) content and uptake at 30, 60 and 90 days after transplanting (DAT) and at harvest. Results revealed that ICM significantly outperformed NF across all growth and yield parameters. Mean plant height under ICM was 99.9 cm compared to 81.6 cm under NF at 90 DAT. Grain yield was substantially higher under ICM (4265 kg ha⁻¹) compared to NF (2233 kg ha⁻¹). Dry matter production under ICM reached 9921 kg ha⁻¹ at 90 DAT against 4969 kg ha⁻¹ under NF. Nutrient content and uptake of N, P and K were consistently higher under ICM at all crop stages. The statistically significant differences ($p < 0.05$) between the two systems highlight the superior productivity of ICM, while also underscoring the need for long-term sustainability research on natural farming approaches.

Keywords: Natural farming, integrated crop management, *Oryza sativa*, plant growth, nutrient uptake, grain yield

Introduction

Rice (*Oryza sativa* L.) is the primary staple food crop for more than half of the global population, particularly in Asia, where it provides the bulk of daily caloric intake (Khush, 2005, Anantha *et al.*, 2024) ^[12, 1]. India is one of the world's leading rice producers, with paddy cultivation covering approximately 44 million hectares annually (FAOSTAT, 2022) ^[5]. In Telangana and other rice-growing states of India, paddy forms the backbone of agricultural economy and food security (TNAU, 2020) ^[23].

Conventional agriculture, driven by the Green Revolution's paradigm, relies heavily on synthetic chemical inputs including inorganic fertilizers, pesticides, and herbicides. While this approach has delivered impressive yield gains, it has simultaneously contributed to soil health degradation, groundwater contamination, greenhouse gas emissions and declining farm profitability due to escalating input costs (Tilman *et al.*, 2002, Chaitanya *et al.*, 2017) ^[22, 3]. These concerns have prompted renewed interest in alternative farming systems that prioritize ecological sustainability.

Natural Farming (NF), rooted in the philosophy of Masanobu Fukuoka (1978) ^[6] and popularized in India through the Zero Budget Natural Farming (ZBNF) framework advocated by Subhash Palekar, seeks to eliminate synthetic inputs entirely. NF relies on biologically active preparations such as Jeevamrutha (fermented microbial inoculant), Bijamrutha (seed treatment) and Mulching to promote soil microbial activity, nutrient cycling and plant health (Chaitanya *et al.*, 2026) ^[4]. Proponents claim that NF can sustain adequate yields while dramatically reducing input costs and improving long-term soil fertility.

Integrated Crop Management (ICM), on the other hand, represents a science-based approach that combines optimal use of chemical fertilizers with good agronomic practices to maximize

productivity and efficiency. ICM integrates soil health management, balanced fertilization based on recommended doses and judicious pest and disease management (Pretty, 2007) [18]. ICM is presently the dominant recommended package of practices in most rice-growing regions of India. Despite growing policy interest in NF exemplified by Andhra Pradesh's large-scale ZBNF promotion comparative, field-level scientific data on crop performance between NF and ICM remain limited (Khadse *et al.*, 2017) [11]. Most evaluations of NF in peer-reviewed literature either lack rigorous experimental controls or are confined to short durations. Therefore, a rigorous, farmer-field-based comparative assessment is imperative to generate evidence-based insights for policymakers, extension workers and farmers.

The present study was designed to compare the growth parameters, yield attributes, dry matter accumulation and nutrient (N, P, K) content and uptake of paddy under ICM and NF during *Kharif* 2021, using a paired farmer-field approach.

2. Materials and Methods

2.1 Experimental Site and Design

The present study was conducted at the Regional Agriculture Research Station, Jagtial (18°45' N, 78°45' E, 71 m above sea level), Telangana state, semi-arid eco-region of India during *Kharif* 2021 at eight plots. Plots were selected in pairs: one managed under ICM and one under NF with comparable soil type, irrigation source and rice variety. The experimental design was a randomized paired-field layout with eight replications (n = 8 per treatment).

2.2 Crop and Field Management

In ICM fields, recommended agronomic practices were followed as per PJTSAU guidelines: transplanting of 25-day-old seedlings at 20 cm × 15 cm spacing and application of fertilizers at 120:60:40 kg ha⁻¹ of N:P₂O₅: K₂O in split doses. Pest and disease management was carried out using chemical pesticides when threshold levels were crossed. Natural Farming fields followed the seed treatment with Bijamrutha, soil application of Jeevamrutha at 200 L ha⁻¹ fortnightly and mulching with crop residues. No synthetic

fertilizers, pesticides or herbicides were used. Transplanting was done at similar spacing as ICM.

2.3 Observations and Measurements

Growth parameters including plant height (cm) and number of tillers per hill were recorded at 30, 60, and 90 DAT. Yield attributes including panicle length (cm), number of grains per panicle, and number of panicles per hill were recorded at maturity. Dry matter production (kg ha⁻¹) was estimated by sampling five hills per field at 30, 60, and 90 DAT, oven-drying at 65 °C to constant weight, and extrapolating to hectare basis. Grain and straw yield (kg ha⁻¹) were recorded at harvest.

2.4 Nutrient Analysis

Plant samples (shoots) at 30 DAT, 60 DAT, and at harvest (straw and grain separately) were analyzed for nitrogen (N) by the Kjeldahl method (Bremner and Mulvaney, 1982) [2], phosphorus (P) by the vanadomolybdophosphoric acid spectrophotometric method and potassium (K) by flame photometry, following standard procedures (Jackson, 1973; Piper, 1966). Nutrient uptake (kg ha⁻¹) was calculated as: Nutrient uptake (kg ha⁻¹) = Nutrient content (%) × Dry Matter or yield (kg ha⁻¹)/100

2.5 Statistical Analysis

Data were subjected to Student's paired t-test to evaluate the significance of differences between ICM and NF at each growth stage ($p < 0.05$). Means and standard errors were calculated for each treatment.

3. Results

3.1 Plant Height

Plant height under ICM was consistently and significantly greater than under NF at all three growth stages (Table 1). At 30 DAT, mean plant height in ICM plots was 54.4 cm compared to 46.8 cm in NF plots ($p = 0.00001$). The difference widened progressively through the crop growth period at 60 DAT, the respective values were 93.9 cm and 77.3 cm and at 90 DAT, 95.2 cm and 79.6 cm. The highly significant p -values (< 0.05 at all stages) confirm that ICM promoted superior vegetative growth due to assured, balanced nutrition from inorganic fertilizers.

Table 1: Effect of modern and natural farming on plant height of paddy crop at 30 DAT, 60 DAT and 90DAT during *Kharif*, 2021

S. No	Plant Height (cm)					
	30 DAT		60 DAT		90 DAT	
	ICM	Natural farming	ICM	Natural farming	ICM	Natural farming
1	54.6	48.0	94.6	76.0	95.8	80.6
2	55.4	44.8	90.8	78.8	91.2	80.6
3	52.6	49.4	96.4	71.6	98.0	79.4
4	53.2	47.8	95.6	85.0	87.6	78.8
5	52.8	46.2	91.0	76.4	94.0	78.0
6	54.6	47.4	94.0	73.6	94.4	76.8
7	58.2	46.2	94.8	76.8	102.4	82.6
8	53.8	44.8	93.6	79.8	98.4	80.0
Mean	54.4	46.8	93.9	77.3	95.2	79.6
p value (t-test) <0.05	0.00001		0.00001		0.00001	

ICM = Integrated Crop Management; NF = Natural Farming; DAT = Days After Transplanting; $p < 0.05$ indicates statistical significance (paired t-test).

3.2 Number of Tillers per Hill

Tiller production showed a more complex pattern (Table 2). At 30 DAT, ICM plots produced a mean of 17.2 tillers per hill while NF plots had 13.0 tillers per hill ($p = 0.000284$).

However, by 60 DAT, ICM plots recorded significantly higher tillering (17.0 tillers/hill) compared to NF (13.7 tillers/hill; $p = 0.019706$). At 90 DAT, ICM averaged 7.8 effective tillers/hill versus 4.4 in NF ($p = 0.006307$).

Table 2: Effect of modern and natural farming on No of Tillers/Hill of paddy crop at 30 DAT, 60 DAT and 90 DAT during Kharif, 2021

S. No	No of Tillers/Hill					
	30 DAT		60 DAT		90 DAT	
	ICM	Natural farming	ICM	Natural farming	ICM	Natural farming
1	14.2	12.6	8.0	13.4	12.0	6.8
2	16.6	9.4	17.6	10.0	8.2	6.0
3	20.8	13.8	19.6	13.8	8.2	8.0
4	17.4	13.0	18.0	13.8	7.2	5.4
5	15.0	14.0	16.0	14.8	8.8	6.6
6	15.8	13.6	19.4	14.4	6.0	5.6
7	18.6	14.0	18.4	15.6	9.4	7.6
8	19.4	13.2	19.2	13.6	7.8	4.4
Mean	17.2	13.0	17.0	13.7	7.8	4.4
p value (t-test) <0.05	0.000284		0.019706		0.006307	

ICM = Integrated Crop Management; NF = Natural Farming; DAT = Days After Transplanting.

3.3 Yield Attributes

Panicle length, grains per panicle and panicles per hill at harvest (90 DAT) all favored ICM over NF (Table 3). Mean panicle length was 22.8 cm under ICM versus 20.8 cm under NF ($p = 0.001839$). The number of grains per panicle was markedly higher under ICM (98.8) compared to NF (66.9; $p = 0.001168$). Panicles per hill at 60 DAT were significantly higher under ICM (5.9 vs. 4.4; $p = 0.006078$), while panicles per hill at 90 DAT showed no statistically significant difference between systems (8.9 in ICM vs. 6.6 in NF; $p = 0.17094$). The higher number of filled grains per panicle under ICM is directly attributable to better assimilate supply during reproductive growth enabled by balanced inorganic nutrition.

Table 3: Effect of modern and natural farming on panicle length, no. of grains/panicle and no. of unfilled grains per panicle and no. of panicle per hill of paddy crop during Kharif, 2021

S. No	Panicle Length (cm)		No. of Grains/Panicle		No. Panicles/Hill			
					60 DAT		90 DAT	
	ICM	N.F	ICM	N.F	ICM	N.F	ICM	N.F
1	22.2	20.8	81.2	44.2	7.8	5.6	4.2	6.4
2	22.8	19.4	106.2	55.8	5.8	4.4	10	4.8
3	20.8	20	84.4	76.4	5.8	4.4	11.2	6
4	22.8	19.4	75	78.8	5	4	9.8	6.8
5	23.8	22.4	115.8	66.8	5.8	4.8	7	7.4
6	22.8	22.8	89.6	73	4.8	4	10.6	7.6
7	24	20.6	98.4	66.2	7.2	5	9.2	7.6
8	23	21	139.8	73.8	5.2	2.6	9.4	5.8
Mean	22.8	20.8	98.8	66.9	5.9	4.4	8.9	6.6
p value (t-test) <0.05	0.001839		0.001168		0.006078		0.17094	

ICM = Integrated Crop Management; NF = Natural Farming; Panicle L = Panicle Length (cm).

3.4 Dry Matter Production

Dry matter production was substantially higher under ICM at all growth stages (Table 4). At 30 DAT, mean dry matter production under ICM (4864 kg ha⁻¹) was more than double that of NF (2379 kg ha⁻¹; $p = 0.00031$). This differential widened at 60 DAT (5674 kg ha⁻¹ in ICM vs. 3068 kg ha⁻¹ in NF; $p = 0.00001$) and at 90 DAT (9921 kg ha⁻¹ in ICM vs. 4969 kg ha⁻¹ in NF; $p = 0.00001$). Dry matter accumulation is a reliable integrative indicator of photosynthetic capacity, source strength, and nutrient availability. The superior dry matter production under ICM

reflects the sustained and balanced nutrient supply from inorganic fertilizers ensuring maximum leaf area index and photosynthate partitioning.

Table 4: Effect of modern and natural farming on Dry Matter Production (kg ha⁻¹) of paddy crop during Kharif, 2021

S. No	Dry Matter Production (kg ha ⁻¹)					
	30 DAT		60 DAT		90 DAT	
	ICM	N.F	ICM	N.F	ICM	N.F
1	4556	2453	6453	3307	10881	5104
2	7876	2418	4231	2422	9096	4307
3	5644	1889	4956	3222	9454	5867
4	3667	3431	5009	3649	10027	5107
5	4773	2644	7507	3271	8568	4975
6	4871	2818	5587	2787	11474	5004
7	2836	1893	6031	3173	9646	5067
8	4689	1489	5618	2716	10222	4317
Mean	4864	2379	5674	3068	9921	4969
p value (t-test) <0.05	0.00031		0.00001		0.00001	

ICM = Integrated Crop Management; NF = Natural Farming.

3.5 Grain and Straw Yield

Both grain and straw yield were significantly higher under ICM than NF (Table 5). Mean grain yield under ICM was 4265 kg ha⁻¹, which was approximately 47.6% higher than NF (2233 kg ha⁻¹; $p = 0.00001$). Similarly, straw yield under ICM (5656 kg ha⁻¹) was significantly greater than NF (3025 kg ha⁻¹; $p = 0.00001$). The grain yield gap of approximately 2032 kg ha⁻¹ between ICM and NF is economically substantial. The lower grain yield in NF fields is consistent with the limited availability of easily plant-available nutrients, particularly nitrogen, during the critical stages of panicle initiation, anthesis and grain filling.

Table 5: Effect of modern and natural farming on straw and grain yield (kg ha⁻¹) of paddy crop during Kharif, 2021

S. No	Straw Yield (kg ha ⁻¹)		Grain Yield (kg ha ⁻¹)	
	ICM	N.F	ICM	N.F
1	5841	2954	5040	2950
2	4586	2657	4510	1950
3	6214	3457	3240	2410
4	5657	3247	4370	2070
5	4998	3175	3570	1900
6	6354	2894	5120	2110
7	5486	3127	4160	2640
8	6112	2687	4110	1830
Mean	5656	3025	4265	2233
p value (t-test) <0.05	0.00001		0.00001	

ICM = Integrated Crop Management; NF = Natural Farming; All yields in kg ha⁻¹.

3.6 Nutrient Content

Nitrogen content of paddy plants was higher under ICM at all crop stages (Table 6). At 30 DAT, N content was 1.10% (ICM) vs. 1.00% (NF). At 60 DAT it was 0.92% (ICM) vs. 0.80% (NF), and in straw at harvest 0.58% (ICM) vs. 0.48% (NF). Grain N content at harvest was 0.88% (ICM) vs. 0.81% (NF). Phosphorus content was also higher under ICM across all stages, while K content showed minor differences, being marginally higher under NF at 30 DAT (1.67% vs. 1.64%) but lower at subsequent stages. These patterns align with the higher crop biomass and larger nutrient sink under ICM.

Table 6: Effect of modern and natural farming on major nutrient content (%) at 30DAT, 60 DAT and harvest of paddy crop during *Kharif*, 2021

Nutrient Content (%)							
S. No	Crop Stage	N		P		K	
		ICM	N.F	ICM	N.F	ICM	N.F
1	30 DAT	1.10	1.00	0.17	0.15	1.64	1.67
2	60 DAT	0.92	0.80	0.16	0.13	1.37	1.28
3	Straw Harvest	0.58	0.48	0.12	0.11	1.45	1.21
4	Grain	0.88	0.81	0.24	0.18	0.22	0.22

ICM = Integrated Crop Management; NF = Natural Farming; N = Nitrogen; P = Phosphorus; K = Potassium (all values in%).

3.7 Nutrient Uptake

The total nutrient uptake (N, P, and K) by the paddy crop was markedly higher under ICM at all crop stages and in grain (Table 7). At 30 DAT, N uptake was 50.91 kg ha⁻¹ under ICM versus 23.89 kg ha⁻¹ under NF. By 60 DAT, N uptake increased to 53.73 kg ha⁻¹ (ICM) and 24.82 kg ha⁻¹ (NF). Straw N uptake at harvest was 32.70 vs. 14.44 kg ha⁻¹, and grain N uptake was 37.48 vs. 17.95 kg ha⁻¹ for ICM and NF respectively. The pattern was similar for P and K uptake, with ICM consistently recording approximately double the nutrient uptake compared to NF. This higher nutrient uptake in ICM is a direct consequence of greater dry matter accumulation and higher nutrient concentrations in plant tissue, together reflecting superior nutrient use efficiency when adequate nutrients are supplied.

Table 7: Effect of modern and natural farming on major nutrient uptake at 30 DAT, 60 DAT and harvest of paddy crop during *Kharif*, 2021

Nutrient uptake (kg ha ⁻¹)							
S. No	Crop Stage	N		P		K	
		ICM	N.F	ICM	N.F	ICM	N.F
1	30 DAT	50.91	23.89	8.7	3.4	76.76	38.76
2	60 DAT	53.73	24.82	8.9	4.0	78.32	39.21
3	Straw Harvest	32.70	14.44	6.83	3.27	81.99	36.37
4	Grain	37.48	17.95	9.98	4.05	9.29	4.99

ICM = Integrated Crop Management; NF = Natural Farming; N = Nitrogen; P = Phosphorus; K = Potassium; all values in kg ha⁻¹.

4. Discussion

The results of this study demonstrate that ICM significantly outperforms NF on paddy growth, yield, and nutrient dynamics over a single *Kharif* season. The marked advantage of ICM in plant height, dry matter production, and grain yield is consistent with the well-established role of nitrogen as the most yield-limiting nutrient for rice (Peng *et al.*, 1996). Applied N under ICM at 120 kg ha⁻¹ would be expected to drive greater leaf area development, chlorophyll content, and photosynthetic rate, ultimately translating into superior biomass accumulation and grain filling.

The approximately 47.7% yield gap (4265 kg ha⁻¹ in ICM vs. 2233 kg ha⁻¹ in NF) is nearer to some comparisons reported in the literature. Khadse *et al.* (2017) [11] documented that ZBNF yields ranged from 60-90% of conventional yields, particularly in the short term. Our findings are in agreement with studies that show significant yield depression in fully organic or natural farming systems in the absence of external nutrient inputs in the short term (Gomiero *et al.*, 2011; Seufert *et al.*, 2012) [8, 21].

The nutrient uptake data reveal that ICM crops took up approximately twice as much N, P, and K at each growth stage compared to NF crops. This large difference confirms

that NF crops were operating under significant nutrient deficiency stress. The Jeevamrutha-based biological inputs used in NF can stimulate microbial activity and nutrient mineralization, but the rate of nutrient release from organic substrates is typically slow and often insufficient to meet crop demand at peak growth stages, especially during panicle initiation and grain filling (Ju *et al.*, 2009; Ladha *et al.*, 2005) [10, 13].

The higher tiller number under NF at 30 DAT merits discussion. Initial tillering in rice is driven by the availability of carbohydrates and a moderate N supply. Under NF, the application of Jeevamrutha at transplanting may have temporarily enhanced N mineralization, providing adequate early-stage nutrition. However, the sharp decline in NF tiller numbers at 60 and 90 DAT suggests that this early benefit was not sustained, likely due to insufficient nutrient supply during the active tillering and panicle development phases.

The findings of this study must be interpreted within the context of a single-season, cross-sectional comparison. It is important to acknowledge that NF systems are typically designed to transition over multiple years, during which soil microbial biomass, organic matter, and biological nutrient cycling capacity are expected to improve progressively (Reganold and Wachter, 2016) [20]. Long-term studies comparing ICM and NF may reveal narrowing of the yield gap as soil health improves under NF. Furthermore, NF's potential advantages in reduced input costs, improved soil biological health, and lower environmental footprint need to be systematically quantified over multiple cropping seasons (Lori *et al.*, 2017; Gatteringer *et al.*, 2012) [14, 7].

5. Conclusions

This study provides robust field-based evidence that Integrated Crop Management significantly outperforms Natural Farming on all measured parameters of paddy productivity during *Kharif* 2021 in Telangana, India. ICM recorded 47.6% higher grain yield, 46.5% higher straw yield, more than double the dry matter production, and consistently higher NPK content and uptake compared to Natural Farming. The highly significant differences ($p < 0.05$) at all growth stages confirm the superiority of ICM in meeting crop nutrient demands in the short term. While NF shows initial promise in early tillering and may offer long-term ecological benefits, a single-season assessment cannot fully capture the transitional dynamics of NF systems. Long-term, multi-season studies are recommended to assess the sustainability and productivity trajectory of NF relative to ICM, alongside comprehensive economic and environmental analyses.

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