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Research Paper

Performance of low-input agriculture with ZBNF-A case study on groundnut (*Arachis hypogaea* L.)–wheat (*Triticum aestivum* L.) cropping system in Saurashtra region of Gujarat

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ABSTRACT

Sustainable low-cost farming in (groundnut based) cropping system offers a much-needed alternative to conventional input-intensive agriculture. Keeping this in view a field experiment was conducted during rainy (*kharif*) season of 2022–23 at ICAR-Directorate of Groundnut Research, Junagadh, Gujarat on groundnut (*Arachis hypogaea* L.) to evaluate the performance of low-input agriculture with ZBNF (Zero-budget natural farming) *vis-a-vis* others. Experiment was conducted in a split plot design having 3 different farming practices, *viz.* Natural farming (NF); Integrated crop management (ICM or conventional farming); and Organic farming (OF) practices in main plot using 2 cultivars 'GJG-22' (Virginia Bunch) and 'TG 37A' (Spanish Bunch) in large sub plot (~1/100th of a hectare), replicated 8-times. Further, these permanent plots of 3 farming practices were cultivated with wheat (*Triticum aestivum* L.) (two cultivars, *viz.* 'GW 451' and 'Lok 1') in rotation during winter (*rabi*) season of 2022–23 following a residual exhaustive fodder crop of pearl millet [*Pennisetum glaucum* (L.) R.Br.] grown during spring/summer 2021–22 prior to the experimentation. The study revealed that pod yield to the tune of 1,316–1,630 kg/ha was realized with low cost NF (or ZBNF) practice (higher yields with Spanish Bunch) *vis-a-vis* 1,448–1,779 kg/ha in OF practice. On the contrary, higher pod yield of 1,679–1,965 kg/ha was realized with the ICM practice employing improved production technologies. The growth/developmental parameters/values including economics and total system productivity were also higher under ICM practice. Furthermore, higher values in respect of all the groundnut plant attributes including economics and nutrient (NPK) uptake, and its efficiency (NPK uptake/100-kg pod) were evident under ICM practice. Similar crop responses were conspicuous in case of the succeeding wheat crop. Thus, overall crop response to farming practices were in the order: ICM>OF>NF; and the ratio of N, P, and K uptake for realization of higher per unit productivity (across farming practices and varieties) was observed to be 6.8:1.0:2.2 for groundnut and 3.9:1.0:3.3 for wheat. Thus, ICM practice comprising of judicious use of chemical fertilizers, manure and pesticides use was advantageous for realizing higher yield and return in groundnut-wheat. Further efforts are made to realize higher productivity of ecofriendly farming practices (ZBNF and OF).

Key words: Conventional farming (ICM), Groundnut-wheat, Low-input agriculture, Organic farming, Saurashtra region, Zero-budget natural farming (ZBNF)

Farmers all across the world used to grow natural (or organic) food before the 1940s when the population was much lower than it is now, and yields were comparable to those of prehistoric times. As the world's population rose, growing food naturally was no longer a viable option for feeding the world's population. To ensure food and nutritional security for the growing population and to increase income, there is an urgent need to enhance resource use efficiency, reduce input costs and improve crop performance in terms of economic parts (yields). According to the International Food Policy Research Institute (IFPRI), the world needs to double food production per unit area/day to feed its estimated 10 billion population by 2050. This calls for an urgent need to identify potential alternative farming strategies to achieve long-term sustainable food production and security (Kumar *et al.,* 2020b). Further, to meet the food demand of increasing population, farmers are attracted towards the use of more and more agro-chemicals in order to gain higher yield(s) over short time (season or year). Indian farmers, mostly categorized under marginal and small, increasingly find themselves in a vicious cycle of debt, because of the high production costs, high interest rates for credit, volatile market prices of

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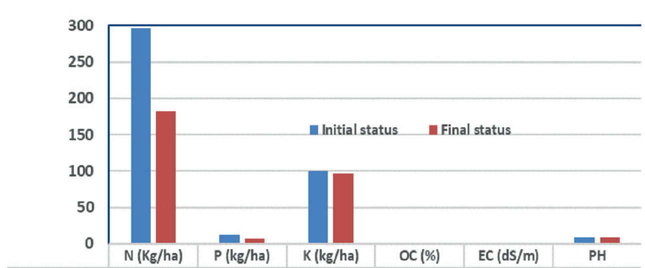
crops, rising costs of fossil fuel based inputs, and higher dependency on seeds produced by private stake holders. In addition, indiscriminate use of chemical fertilizers and pesticides posed a threat to both the living media i.e., the soil and environment (Singh *et al.,* 2021). Many investigations have revealed the adverse effects of chemical fertilizers through change in soil nature, soil contamination, ground water pollution, decrease in soil micro flora, and so on (Malik *et al*., 2017).

Crops or cropping systems play a crucial role in sustainability of the region as these meet out the demand for seeds/grains in that region. For example, groundnut (*kharif*)-wheat (*rabi*) is an important cropping system in India as a whole and the state of Gujarat in particular especially under (partially) irrigated agro-climatic condition. The major factor contributing optimum yields of these diverse component crops (one is for edible oil and other is staple grain) is soil fertility and its maintenance (over time across location). There are indications of stagnation and even decline in the productivity of these crops due to decrement in SOM (Soil Organic Matter), deficiency of secondary and micronutrients (including hidden hunger) and non-availability of cost effective/efficient manures and fertilizers suitable for the agro-ecology at appropriate time. Farmyard manure (FYM) is the most important organic source to supplement nutrient capacity of the soil but its non-availability and/or very high cost necessitates searching of other alternate sources for restoration of soil fertility. Alternatively, farm wastes including crop/root residues/litters are having potential to use as the cheapest source of organic matter. Therefore, reduction in cost of cultivation (scaling/doubling farm income, DFI) and/or raising productivity are highly demanding now than ever before (Praharaj *et al.,* 2006). More recently, on the former context, emphasis on natural products (or Natural farming) as an exercise towards both cost cutting and premium enterprises promoted by both government (public) and private stakeholders needs its application for further evaluation/fine-tuning. Moreover, although natural farming practices could be seen as one of the alternative options for the producers and the consumers for chemical-free produce, and its produce be recognized as niche product, yet, greater scientific evidences need to be generated before scaling out in different agro-climatic regions with different crop combinations for its viability and long-term sustainability (Kumar *et al.,* 2020a). In addition, economic survey (2019) of India also categorized alternative farming practices, like Natural farming or ZBNF as one of the organic farming models. It also highlights the elimination of agro-chemicals for sustaining agricultural production with eco-friendly processes in tune with (nourishment through) nature. Therefore, as all these informations are scattered and deficient in case of natural farming, it calls for an investigation on these points through holistic (qualitative and quantitative) evaluation of different farming practices (NF, OF and ICM practice) in vogue across the country through diverse features (including nutrient availability, uptake, yield and economics) in major cropping systems. Here, in south Gujarat region, more popularly called Saurashtra region, the dominant cropping system of groundnut-wheat was selected as a case study to evaluate the performance of low-input agriculture with ZBNF *vis-a-vis* others.

The prevailing agro-ecosystem involves an irrigated tract of alkali soil (with *p*H of 8.24, low available N, P, K, and medium SOC of 0.63%) falling under Southern Saurashtra Agro-climatic Zone of Gujarat, and Gujarat Plain and hill region of India.

MATERIALS AND METHODS

A field experiment was conducted during rainy (*kharif*) season of 2022–23 at ICAR-Directorate of Groundnut Research, Junagadh, Gujarat following sowing of an exhaustive fodder crop of pearl millet to have uniformity at the beginning of experimentation. This residual exhaustive fodder crop was grown prior to *kharif*-sowing of groundnut for eliminating soil heterogeneity, if any. As a result, almost similar nutrient availability in soils (homogeneity) was conspicuous in different plots to start with the experiment involving groundnut-wheat (Fig. 1) in rotation (during *kharif* 2022 and *rabi* 2022–23, respectively). The study area is geographically located in the foothills of Mt Girnar in the historical city of Junagadh in the southern region of Saurashtra (on 21.31^0 North, 70.36^0 E, and 60 m amsl); and is further included under India's Gujarat plain and hill region. The climate of this area is semi-arid with an average rainfall of 800–1000 mm. The *kharif* groundnut was raised entirely during rainy season with seasonal rainfall; while *rabi* wheat was taken up during winter season with irrigation. The soil was calcareous medium black clayey (Vertic stochrept), alkaline in soil reaction (8.24), medium in organic carbon (0.63%) and low in available N (182 kg/ha),



	N (Kg/ha)	P (kg/ha)	K (kg/ha)	OC (%)	EC (dS/m)	PH
Initial status	296.68	12.81	100.05	0.7	0.317	8.24
Final status	182.20	7.95	96.88	0.63	0.39	8.24

Fig. 1. Changes in fertility and other chemical properties of soil before sowing and after harvest of the exhaustive crop of pearl millet (Mean values, 0–15 cm soil depth)

available P (7.95 kg/ha), available K (96.88 kg/ha), and low status of major micronutrients. The bulk density of 0–15 cm and 15–30 cm depth soil was 1.44 g/cc and 1.46 g/cc, respectively. The soil moisture content (0–15 and 15–30 cm profile-depth at field capacity) (1/3rd atmosphere) was 30.4 and 30.3%, respectively; and the permanent wilting point (15 atmosphere) for the same was 14.4 and 14.0%, respectively (resulting in around 16% soil available water). The total rainfall received during the *kharif* growth period was 1214.4 mm with a total of 45 rainy days while scanty rain (13.3 mm in 2 rainy days) was received during winter months.

The experiment was laid out in a split plot design during *kharif* season with groundnut crop sown with 3 farming practices in main plot (Natural farming, ICM practice and organic farming); and 2 varieties of groundnut (Spanish Bunch TG 37A and Virginia Bunch GJG 22) in sub plot. Two varieties of wheat (GW 451 and Lok 1) replaced the groundnut varieties during *rabi* season following a permanent lay-out system for the above 3 farming practices. The treatments were laid out in large plots of ~100 m^2 and replicated 8 times during both *kharif* and *rabi* seasons. The details of the farming modules are presented in Table 1. The detailed methodology about 4 pillars of low-cost natural farming (LCNF or ZBNF) are also presented in Table 2 (Palekar, 2006). The groundnut crop was sown during last week of June, 2022 with pre-sowing irrigation and was harvested during 3rd week of October, 2022; and was

Table 1. Package of practices followed in various treatments under different farming practices

Treatments	Farming practices/Module details
Module-I	*Natural Farming (NF)* • Seed treatment with *Beejamrut* by spraying on seed, mix well and dry before sowing • Soil application of *Ghan Jeevamrut* at 2000 kg/ha along with FYM at sowing as well as soil application of *Jeevamrut* with irrigation at sowing, 30, 60 and 90 DAS* • *Achhadan*: Wheat straw mulch at 5 t/ha • Plant/weed protection: *Agniastra*, *Brahmastra, Neemastra*, etc. if required along with manual weeding
Module-II	*Organic Farming (OF)* • Seed treatment with biofertilizer by spraying on seed, respectively; mix well and dry before sowing • Soil application of vermicompost @2 t/ha, FYM @10 t/ha and foliar application of *Panchagavya* at 30, 45 and 60 DAS • Plant/weed protection: Pheromone trap, *Trichoderma*, *Beauveria*, *Metarhizium*, NPV, etc. if required along with manual weeding
Module-III	*ICM practice* • Seed treated with recommended fungicide before sowing of seed • Soil application of recommended dose of chemical fertilizer and manures • Plant/weed protection: Recommended fungicides, insecticides and herbicides, if required

Table 2. Details of methodology for supplying inputs in natural farming adopted under field condition

Input	Preparation	Benefits
Jivamrita/ Jeevamrutha	It is composed of the cow-dung (20 kg), urine (5–10 l), jaggery (20 kg) and dicot flour (2 kg) and is applied to the crops with each irrigation cycle	It provides nutrients, but most importantly, acts as a catalytic agent that promotes the activity of microorganisms in the soil, as well as increases earthworm activity. It also helps to prevent fungal and bacterial plant diseases. It is only needed for the first 3–4 years of the transition, after which the system becomes self-sustaining
Ghana Jeevamrutha	It is composed of the dry cow-dung (200 kg) and *Jeevamrita* (mixed with dry cow-dung), left 48 h for shade-drying, and applied as basal with 800 kg/ac in 1st year, 500 kg/ac in 2nd year and 200 kg/ac in subsequent years	It is a solid form of *Jeevamrita* used to increase soil fertility by microbial consortia. It can be added to improve the soil health more often in malnutrition soil
Bijamrita	It is basically made up of water (20 litre), cow dung (5 kg), urine (5 litre), lime (50 gm) and just a handful of soil	It is a seed treatment, equipped in protecting young roots from fungus as well as from soil-borne and seed-borne diseases
Acchadana-Mulching	It could be done by soil mulch, straw mulch or live mulch	It conserves soil moisture by reducing evaporation
Whapasa-moisture	The irrigation should be reduced and should be practiced efficiently only in alternate furrows	It challenges the idea that plant roots need a lot of water. In-fact, what roots need is water vapour, and therefore, *whapasa* is the condition where there exist both air molecules and water molecules present in the soil

*DAS, Days after sowing.

followed by wheat (grown from mid-November to mid-March, 2023). The *kharif* groundnut crop was raised mostly with seasonal south-west monsoon while *rabi* wheat with irrigation. Normal practices were followed to raise a successful crop during both the seasons. Measurements on plant growth and development attributes including yield and economics in groundnut-wheat cropping system were taken up. The nutrient analysis revealed that *Bijamrita* contains 2.38% N, 0.127% P, 0.485% K and 282 ppm Fe on dry wt. basis, while the corresponding values for *Jivamrita* were 1.96%, 0.173%, 0.28%, and 15.35 ppm repectively. Farmyard manure contains the average values of 0.5% N, 0.2% P, 0.5% K and 146.5 ppm Fe.

RESULTS AND DISCUSSION

A) Groundnut: Growth and development parameters

Growth parameters of groundnut, *viz.* plant height, fresh and dry weight/plant, nodule count and nodule dry weight were differed significantly due to different farming practices/modules and varieties, whereas the interaction effect was found to be non-significant (Table 4). The nutrient content in input-formulations used in both natural farming (ZBNF) and organic farming is also given in Table 3. It revealed that among three farming practices, significantly higher plant height, fresh and dry weight/plant, nodule count and nodule dry weight were observed in the plots under the organic farming practices which included use of FYM, vermicompost, biofertilizers and plant protection with organic products, like neem oil etc. While, the plots with low cost NF had recorded significantly lower plant height, number of branches/plant at harvest, fresh and dry weight/plant, nodule count and nodule dry weight in both the varieties. And those with conventional farming (ICM) were ranged in between both the above farming practices (i.e., NF and OF). However, higher values of plant parameters (except nodule attributes) were observed under Virginia Bunch GJG 22 (Table 3) owing to its unique growth habit.

Higher crop growth under organic farming practices were due to more favourable soil condition. This included

Table 3. Nutrient content in input-formulations used in different farming practices (NF, OF, and ICM)

Nutrient	*Beejamrut*	*Jeevamrut*	FYM	Vermicompost
N (%)	2.380	1.96	0.5	1.6
P (%)	0.127	0.173	0.2	0.7
K (%)	0.485	0.280	0.5	0.8
Fe (ppm)	282	15.35	146.5	175
Mn (ppm)	10.7	3.32	69.0	96.5
Zn (ppm)	4.29	2.95	14.5	24.5

FYM, Farmyard manure; ICM, Integrated crop management; NF Natural farming; OF, Organic farming.

Table 4. Effect of farming practices and varieties on growth and yield parameters of groundnut

Treatment	Plant height (cm)	Branches/ plant (#/pl)	Fresh wt. (g/pl)	Dry wt. (g/pl)	Nodule count (#/pl)	Nodule dry wt. (mg/pl)	Pod yield (kg/ha)	Haulm yield (kg/ha)	Total yield (kg/ha)	Harvest index (%)
Farming practices (F)										
ICM	32.7	4.01	60.5	18.4	172	58.2	1822	2740	4562	39.9
NF	29.8	4.16	51.1	16.1	174	63.6	1473	2014	3486	42.2
OF	38.5	4.33	66.6	19.0	174	68.7	1613	2564	4178	38.5
SEm±	0.56	0.14	2.19	0.50	2.65	1.66	24.3	14.3	30.0	0.37
CD (P=0.05)	1.74	NS	6.73	1.54	NS	5.07	74.3	43.7	92.0	1.14
Varieties (V)										
TG 37A	27.6	3.73	53.7	16.8	185	71.0	1791	2458	4249	42.1
GJG 22	39.8	4.60	65.2	18.8	161	56.0	1481	2420	3901	38.3
SEm±	0.57	0.13	2.14	0.52	2.24	1.31	21.9	13.3	27.7	0.32
CD (P=0.05)	1.69	0.39	6.36	1.54	6.64	3.87	65.1	NS	82.0	0.96
Interaction (F x V)										
SEm(±)	0.80	0.20	3.10	0.71	3.69	2.34	34.3	20.2	42.5	0.53
CD (P=0.05)	2.98	NS	NS	NS	NS	6.82	NS	69.1	144.2	1.68
Interaction (V x F)										
SEm±	0.90	0.21	3.42	0.81	3.79	2.30	36.2	21.6	45.3	0.54
CD (P=0.05)	2.71	NS	NS	NS	NS	6.94	NS	65.0	136.2	1.64

ICM, Integrated crop management; NF, Natural farming; OF, Organic farming.

soil application of vermicompost, FYM, biofertilizers and biopesticides. Vermicompost is rich in N, P, K, different plant hormones and micronutrients that regulates plant metabolism at cellular level and cast/residues produced by worm feeding on organic substrates are extremely homogeneous, and fertile (material) suitable for plant growth. Moreover, the presence of plant hormones fastens cell division and cell elongation. Vermicompost provides food for the bacterial growth and metabolic activities, and presence of higher amount of hormones and balanced *p*H also maintain the favourable environment that results in maximum growth of bacteria present in root nodules. This might be the reason for the maximum number of root nodules and dry weight of nodules/plant under both organic and natural farming over the ICM practice in groundnut crop (a legume). However, conversion of these (N fixed etc.) to yield is important. These results are in conformity with the findings of Sitaram *et al*., 2014.

Yield and yield attributes: Different farming practices/ modules exerted significant influence on yield and yield attributes of groundnut crop as a consequence of favourable growth and development attributes. Pod yield to the tune of 1,316–1,630 kg/ha was realized with low cost natural farming (NF) practice (based on interaction data depending on the farming practice/varieties; and higher yields with Spanish Bunch) *vis-a-vis* 1,448–1,779 kg/ha in organic farming (OF) practice (Table 4). However, maximum yield to the extent of 1,679–1,965 kg/ha was realized with ICM practice employing improved production technologies as per recommended practice (these ranges in pod yields are evident from two-way interaction of treatments involving farming practice × varieties). This was in fact contrary to the trend observed for some of the growth attributes (Table 4). However, the maximum values in respect of certain key after-harvest parameters, *viz.* haulm yield (2740 kg/ha), kernel yield (1259 kg/ha) and 100-kernel wt. (35.2g) were recorded under ICM practice only (Table 5). Although higher values in respect of harvest index (42.2%) were observed under NF practices, yet higher increases in terms of yield and associated yield traits in case of ICM might be owing to appropriate enhancement in yield attributes, *viz.* seed index, shelling per cent and haulm yield (under ICM, Table 5). Consequently, the cumulative effect of all these resulted in higher increments in both pod and kernel yields under ICM. Similar observations were made by Nath *et al*., (2023a). Thus, it was inferred from the above that although groundnut crop poorly responded to low cost natural farming (with 19% lower yield over ICM), yet the later ICM practice based on integrated nutrient management comprising of chemical fertilizers, FYM and pesticides was advantageous for realizing higher yield from groundnut crop.

The effect of the main plot (farming practice) revealed that significantly higher values of yield and its parameters were recorded in the order of: ICM>OF>NF; while on sub plot front, significantly greater productivity was recorded under Spanish Bunch TG 37A compared to Virginia Bunch GJG 22. The values of all the growth and developmental parameters were also higher under the above treatment (TG 37A) although higher values of some of the plant param-

Table 5. Effect of farming practices and varieties on yield attributes and economics of groundnut

Treatment	Pods/ plant (#/pl)	Seed index (g)	Shelling per cent (%)	Kernel yield (kg/ha)	Gross return (₹/ha)	Net return (₹/ha)	B:C ratio
Farming practices (F)							
ICM	13.5	35.2	69.24	1,259	1,12,081	67,267	2.50
NF	14.4	31.5	68.18	1,002	89,772	53,348	2.47
OF	14.9	33.2	69.19	1,116	99,801	56,301	2.29
SEm (±)	0.34	0.21	0.25	18.1	1,357	1,358	0.03
CD (P=0.05)	1.04	0.64	0.77	55.4	4,157	4,158	0.10
Varieties (V)							
TG 37A	13.2	29.6	67.88	1,216	1,09247	67,667	2.63
GJG 22	15.3	37.1	69.86	1,035	91,856	5,0276	2.21
SEm (±)	0.49	0.23	0.33	14.22	1,230	1,231	0.03
CD (P=0.05)	1.45	0.68	0.97	42.12	3,644	3,644	0.09
Interaction (F × V)							
SEm(±)	0.48	0.29	0.35	25.59	1,919	1,919	0.05
CD (P=0.05)	2.53	NS	1.70	NS	NS	NS	NS
Interaction (V × F)							
SEm(±)	0.69	0.35	0.47	25.12	2,028	2,028	0.05
CD (P=0.05)	2.06	NS	1.42	NS	NS	NS	NS

ICM, Integrated crop management; NF, Natural farming; OF, Organic farming.

eters were observed under Virginia Bunch GJG 22 (Table 4, 5). As a result and quite similar to ICM, TG 37A outperformed over GJG 22 in respect of both pod and kernel yield. More specifically, higher haulm yield and harvest index under TG 37A contributed towards significant increase in yield in the variety compared to GJG 22. Interaction effect on pod yield was not significant (Table 4). Higher yield of groundnut as evident following application of inorganic sources of nutrient might be owing to appropriate availability and immediate release of nutrients to these short duration varieties needing quick nourishment compared to organic sources of nutrient that release the nutrients slowly (Nath *et al.,* 2023a,b). The findings corroborate with Banik and Sharma (2009) who found similar results for soil with relatively high organic carbon levels.

Economics of improved practice: As a result of higher yields, ICM practice in groundnut registered significantly higher gross returns (₹1,12,081/ha) and net returns (₹67,267/ha), followed by OF and NF (Table 5). In fact, NF reported significantly lower gross returns (₹89,772/ha) and net returns (₹53,348/ha) owing to lesser yield and biomass realized under the farming practice. Similarly, higher B:C ratio (2.50) was recorded under ICM, followed by low cost natural farming (NF) and organic farming (OF). This might be attributed to higher economical and biological yield of crops realized under ICM with similar cost to that of organic/natural farming practices. Similar was the case for Spanish Bunch TG 37A compared to Virginia Bunch GJG 22 (Table 5). In fact, higher yield realized with TG 37A resulted in realization of significantly higher income and BCR over those in GJG 22. Similar results were also reported by Chaurasia *et al*., (2009), Behera and Rautaray (2010), Singh *et al*., (2018) and Lyngdoh *et al*., (2019).

B) Wheat: Yield and its traits

Various farming practices/modules exerted significant influence on yield and yield attributes of rotational wheat crop also. Under existing agro-climatic condition of Sourashtra region, wheat grain yield to the tune of 3,156 kg/ha was realized with low cost NF practice *vis-a-vis* 3,947 kg/ha in OF practice (Table 6). However, significantly higher yield of 5,300 kg/ha was realized with ICM practice employing improved production technologies as per recommended practice. It was evident that similar to groundnut, wheat crop also poorly responded to low cost natural farming (with 40% lower yield over ICM). Similar was the trend for other growth/yield attributes i.e. maximum straw yield (6439 kg/ha), biological yield (11.7 t/ha), dry weight of plants at harvest (215 g/m row length), no of panicles/m row length (90.1) and seed index (58.2 g) were recorded under ICM although slightly higher values in respect of only harvest index (47.4%) was observed in case of NF practices (Table 6). As a consequence of all these, economics of crop production was in favour of ICM plots and the highest net return and BC ratio (3.79) was obtained in the plots practiced with ICM.

Thus, on wheat crop, the main plot effect (farming practice) was evident in the order of: ICM>OF>NF; while on sub plot front, significantly greater productivity was recorded in plots grown with wheat GW 451 compared to Lok 1. The values of all the growth and developmental parameters were also similarly affeced and recorded higher under the variety GW 451. Interaction effect on growth parameters was mostly not significant except for yield and economics. It was inferred from the above that higher yield of wheat following application of inorganic sources of nutrient might be owing to higher availability and release of

Table 6. Effect of farming practices and varieties on agro-economic attributes of wheat

Treatment	Grain yield (kg/ha)	Straw yield (kg/ha)	Biological yield (t/ha)	Harvest index (%)	Dry wt. (g/m row length)	No. of panicles/ m row length	Seed index (g/1000-seed)	Gross return (₹/ha)	Net returns (₹/ha)	B:C ratio
Farming practices										
ICM	5300	6439	11.7	45.1	215	90.1	58.2	119062	87621	3.79
NF	3156	3503	6.66	47.4	138	68.1	53.2	70561	45836	2.85
OF	3947	4979	8.93	44.2	184	74.5	56.6	88855	57532	2.84
SEm(±)	104	113	0.21	0.41	7.45	3.67	0.76	2291	2291	0.08
CD (P=0.05)	317	347	0.63	1.26	22.8	11.3	2.34	7015	7015	0.26
Varieties										
GW 451	4464	5429	9.89	45.3	186	80.1	54.0	100285	71123	3.40
Lok 1	3805	4519	8.32	45.9	173	75.1	58.0	85366	56204	2.92
SEm(±)	70.4	56.6	0.10	0.44	4.02	2.09	0.42	1514	1514	0.05
CD (P=0.05)	208	168	0.31	NS	11.9	NS	1.24	4484	4484	0.15
Interaction	*	*	*	NS	NS	NS	NS	*	*	*

*Significant at *P*<0.05. ICM, Integrated crop management; NF, Natural farming; OF, Organic farming.

nutrients to these short duration varieties needing a quick nourishment as compared to organic sources of nutrient (Nath *et al.,* 2023a). The findings corroborate with those of Banik and Sharma (2009).

C) Cropping system productivity and economics

Various farming practices/modules again exerted significant influence on yield and its attributes of groundnut-wheat cropping system as a whole following its pertinent effects on both the component crops (groundnut and wheat). Based on groundnut equivalent yield (GEY), total pod yield to the tune of 2,681 kg/ha was realized with low cost NF practice *vis-a-vis* 3,125 kg/ha in OF practice (Table 7). However, significant higher yield to the tune of 3,851 kg/ha was realized with ICM practice employing improved production technologies. Similar was the trend for other growth/yield attributes under ICM practice, viz. total biomass productivity (16.3 t/ha), productivity per day (72.8 kg/ha/day), and other parameters including economic benefits (with net return of ₹1,54,888 and BCR of 3.03). Thus, the effect of main plot (farming practice) followed the same trend as in above (ICM>OF>NF on both yield and economics front); while in sub plot (varieties of groundnut-wheat), significantly greater productivity was recorded under TG 37A- GW 451 compared to GJG 22-Lok 1. The values of all the growth and developmental parameters were also similarly influenced under the above combination. Interaction effect on growth parameters was mostly significant (Table 7) thereby indicating comparable higher crop responses observed in case of the combination of ICM practice and TG 37A-GW 451. As explained above, the higher total yield of groundnut-wheat following application of inorganic sources of nutrient might be owing to higher availability and release of nutrients to these crops in the ICM practice compared to organic and natural source of nutrient that release the nutrient slowly. The findings corroborate with those of Banik and Sharma (2009). Thus, it was inferred from the above that groundnut-wheat (the cropping system as a whole) poorly responded to low cost natural farming (with 30% lower yield over ICM in terms of total GEY), yet, ICM practice based on integrated nutrient management involving chemical fertilizers, FYM and pesticides was advantageous for realizing highest yield/return of all the three practices evaluated (Table 7).

D) Nutrient content and uptake

Various farming practices/modules exerted similar and significant influence on nutrient (NPK) uptake and their production efficiency (Kg nutrients required for 100-kg pods produced under the existing condition/season as constrained by farming practices) in the main crop of groundnut. In fact, N, P, K and total nutrient (NPK) uptake was the highest under ICM plots, while the lowest uptake was with natural farming (Table 8). Keeping in view of higher productivity, the mean uptake for N, P and K (inclusive of both kernel and haulm in groundnut crop only) in respect of ICM practice were to the tune of 97.9, 14.23 and 30.7 kg/ha (compared to the lowest values of 62.5, 9.28 and 20.1 kg/ha under NF, respectively). Similar values/responses were obtained in case of rotational wheat crop also (Table 9). As per uptake of nutrients was concerned, the treatments followed the order similar to above: ICM>OF>NF; TG 37A>GJG 22 (groundnut); GW 451>Lok 1 (wheat). Interaction effect on growth parameters was mostly significant thereby indicating the higher crop response in respect of nutrient (s) uptake in the combination of ICM and TG 37A (both having higher individual effect).

Table 7. Effect of different farming practices and varieties on productivity and economics of groundnut-wheat cropping system

Treatment	Total yield# (kg/ha)	Total biomass productivity (t/ha)	Productivity per day* (kg/ha)	Gross return (₹/ha)	Net returns (₹/ha)	Benefit cost ratio
Farming practices						
ICM	3851	16.3	72.8	231143	154888	3.03
NF	2681	10.1	45.3	160334	99185	2.62
OF	3125	13.1	58.5	188656	113833	2.52
SEm±	45.6	0.20	0.91	2604	2604	0.04
CD (P=0.05)	140	0.62	2.78	7976	7976	0.12
Varieties						
GW 451	3500	14.1	63.1	209533	138790	2.95
Lok 1	2937	12.2	54.6	177223	106480	2.50
SEm±	35.2	0.11	0.50	1999	1999	0.03
CD (P=0.05)	104	0.33	1.49	5919	5919	0.08
Interaction	*	*	*	*	*	*

*Total duration=111+113=224 days; # Based on groundnut equivalent yield (GEY)=Groundnut yield+GEY of wheat (kg/ha). ICM, Integrated crop management; NF, Natural farming; OF, Organic farming.

Table 8. Effect of farming practices and varieties on nutrient (NPK) content and uptake by groundnut

Treatment	Nutrient content (%) in seed/haulm			Nutrient uptake (kg/ha) in seed/ haulm			Total nutrient uptake (seed + haulm) (kg/ha)			Total nutrient uptake (seed + haulm) in kg/ 100-kg pod produced		
	N	P	K	N	P	K	N	P	K	N	P	K
Farming practices												
ICM	4.05/ 1.71	0.41/ 0.33	0.99/ 0.67	51.1/ 46.8	5.11/ 9.12	12.4/ 18.3	97.9	14.23	30.7	5.40	0.78	1.70
NF	3.03/ 1.59	0.35/ 0.29	0.91/ 0.55	30.6/ 32.0	3.52/ 5.76	9.08/ 11.1	62.5	9.28	20.1	4.25	0.63	1.37
OF	3.58/ 1.70	0.39/ 0.31	0.96/ 0.63	40.2/ 43.6	4.37/ 7.94	10.7/ 16.2	83.8	12.32	26.9	5.22	0.77	1.68
SEm(±)	0.14/ 0.01	0.006/ 0.005	0.007/ 0.007	0.65/ 0.24	0.07/ 0.04	0.17/ 0.09	0.65	0.08	0.18	0.06	0.008	0.018
CD (P=0.05)	0.55/ 0.04	0.02/ 0.02	0.03/ 0.03	1.99/ 0.73	0.21/ 0.14	0.52/ 0.27	1.98	0.23	0.55	0.17	0.024	0.054
Varieties												
TG 37A	3.72/ 1.69	0.40/ 0.32	0.97/ 0.64	45.7/ 41.7	4.89/ 7.95	11.78/ 15.7	87.4	12.84	27.5	4.86	0.72	1.53
GJG 22	3.39/ 1.64	0.36/ 0.30	0.93/ 0.59	35.6/ 39.9	3.78/ 7.26	9.71/ 14.6	75.5	11.04	24.3	5.05	0.74	1.63
SEm(±)	0.03/ 0.006	0.006/ 0.001	0.003/ 0.004	0.48/ 0.22	0.05/ 0.04	0.13/ 0.08	0.58	0.07	0.17	0.06	0.008	0.020
CD (P=0.05)	0.11/ 0.02	0.02/ 0.005	0.01/ 0.01	1.44/ 0.65	0.16/ 0.12	0.39/ 0.24	1.70	0.22	0.50	0.18	NS	0.058
Interaction CD (P=0.05)*	NS/ NS	NS/ NS	NS/ NS	NS/ 1.15	NS/ 0.21	NS/ 0.42	2.99	0.38	0.88	0.32	0.046	0.102

*Significant at $P<0.05$. ICM, Integrated crop management; NF, Natural farming; OF, Organic farming.

For 100-kg of pods produced under field condition, the mean (nutrient) uptake for N, P and K (inclusive of both kernel and haulm in groundnut crop only) in respect of ICM were to the tune of 5.40, 0.78 and 1.70 kg/ha (compared to the lowest values of 5.22, 0.77 and 1.68 kg/ha under natural farming, respectively). Again, thus, as per uptake of nutrients was concerned per 100-kg of pods produced, the effective farming practices/ varieties were in the same order as in above (ICM>OF>NF; TG 37A> GJG22) (Table 9). Interaction effects on growth parameters followed the same trend. Further, it was calculated that the groundnut crop needs around 7.3 kg NPK i.e. 5.0 N + 0.7 P + 1.6 K/ 100 kg pods under ICM (estimated at around 100 kg N, 14 kg P and 32 kg K per 2 tonnes of average pod yield) and the same quantities may be required for both organic and natural farming provided adequate and appropriate blending of these are made with suitable additives/supplementary nutrients as envisaged by different farming practices (as low yield was associated with lower nutrient uptake). Higher productivity is usually associated with higher nutrient uptake (without limitation of a specific or set of nutrient elements and at similar use-efficiency) which can further be enhanced by appropriate technological innovations and their application/ management provided other limiting factors remain constant. Alternatively, the study showed that pod yield to the tune of 20.5, 139.5 and 64 kg were produced at the expense of 1 kg N, P and K, respectively (partial factor productivity calculated as pod yield per unit nutrient absorbed). Further, based on ratio of N, P, and K uptake higher per unit productivity (calculated across farming practices and varieties) was observed to be 6.8: 1.0: 2.2 for groundnut and 3.9: 1.0: 3.3 for wheat. These results are on accordance with those of Banik and

Table 9. Effect of farming practices and varieties on nutrient (NPK) uptake by wheat

Treatment	Nutrient content (%) in grain/straw			Nutrient uptake (kg/ha) in grain			Nutrient uptake (kg/ha) in straw			Total Nutrient uptake (kg/ha) (grain + straw)		
	N	P	K	N	P	K	N	P	K	N	P	K
Farming practices												
ICM	1.94/ 0.38	0.44/ 0.16	0.54/ 1.22	102.9	23.4	28.6	24.4	10.1	78.3	127.4	33.5	107.0
NF	1.65/ 0.31	0.36/ 0.12	0.47/ 1.09	52.2	11.2	14.8	11.0	4.09	38.0	63.2	15.3	52.8
OF	1.85/ 0.34	0.41/ 0.15	0.52/ 1.16	73.1	16.3	20.4	17.1	7.34	58.0	90.2	23.6	78.4
SEm(±)	0.008/ 0.011	0.007/ 0.006	0.004/ 0.007	1.83	0.41	0.52	0.39	0.16	1.30	2.14	0.54	1.73
CD (P=0.05)	0.033/ 0.045	0.028/ 0.025	0.016/ 0.027	5.61	1.25	1.59	1.19	0.49	3.97	6.56	1.65	5.29
Varieties												
GW 451	1.83/ 0.36	0.41/ 0.15	0.52/ 1.17	83.0	18.9	23.5	19.7	8.49	64.1	102.8	27.4	87.6
LOK 1	1.80/ 0.33	0.39/ 0.13	0.50/ 1.14	69.1	15.0	19.1	15.3	5.88	52.1	84.4	20.9	71.2
SEm(±)	0.002/ 0.002	0.005/ 0.003	0.004/ 0.007	1.32	0.30	0.37	0.20	0.09	0.67	1.39	0.34	0.86
CD (P=0.05)	0.008/ 0.007	0.018/ 0.011	0.016/ NS	3.91	0.88	1.09	0.60	0.26	1.98	4.13	0.99	2.55
Interaction CD (P=0.05)*	NS/ NS	NS/ NS	NS/ NS	6.90	1.56	1.92	1.07	0.46	3.51	7.30	1.76	4.52

* Significant at $P<0.05$. ICM, Integrated crop management; NF, Natural farming; OF, Organic farming.

Sharma (2009).

From the above, it was inferred that integrated crop management (ICM) practice based on integrated management of inputs/practices comprising of chemical fertilizers, manures and pesticides use was useful for realizing higher and stable yield along with better returns from groundnut-wheat cropping system.

Based on the results it can be concluded that *kharif* groundnut-*rabi* wheat poorly responded to natural farming practice with reduction (19% in groundnut, 40% in wheat, and 30% in groundnut-wheat) in yields (and profitability) compared to ICM practice. The later comprising of chemical fertilizers, manure and pesticides was far more superior in realizing higher yield/return of groundnut-wheat cropping system due to adequate input supply as per crop requirement accompanied with favourable crop growth and development. Further efforts are made to realize higher productivity of ecofriendly farming (natural or organic) practices through reinforcement of nutrient appropriately and suitably.

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