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Evaluation of Organic and Conventional Rice Production Systems for their Productivity, Profitability, Grain Quality and Soil Health

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Abstract

Considering the importance of organic farming and growing demand for organically produced foods, field studies were conducted for 5 years (2004-05 to 2009-10) on a black clayey vertisol soil at the Directorate of Rice Research, Hyderabad, to study the influence of organic and conventional farming systems on productivity, grain quality, soil health and economic returns of super fine rice varieties. Two main plot treatments, with and without plant protection, and four sub plot treatments viz., Control; 100% inorganics; 100% organics; and 50% inorganics+50% organics (integrated nutrient management, INM) were imposed. During wet season, grain yields under 100% inorganics and INM were near stable (4.7-5.5 t/ha) and superior to organics by 15-20% during the first two years, which improved with organics (4.8-5.2 t/ha) in the later years to comparable levels with inorganics, while it had taken five years during dry season. Moderate improvement in nutritional quality was recorded with organics, especially in brown rice. There was a significant improvement in soil physical, fertility and biological properties with organics, which resulted in further improvement in soil quality indices. The sustainability index of the soil was maximum with organics (1.63) compared to inorganics (1.33), after five years of study. The soil organic carbon (SOC) stocks were higher with organics by 44 and 35%, compared to conventional system during wet and dry seasons, respectively, after five years of study. The carbon sequestration rate was also positive with organics (0.97 and 0.57 t/ha/yr during wet and dry seasons, respectively), compared to conventional system that recorded negative SOC sequestration rate (-0.21 and -0.33 t/ha/yr during wet and dry seasons, respectively). Benefit cost ratio was less with organics in the initial years and improved later over inorganics by fifth year.

Keywords: Organic rice; Conventional rice; Productivity; Grain quality; Soil health; Economic returns

Introduction

Rice is the major staple food crop in India, occupying around 45 m.ha., and contributing about 100 million tones to the total food grain production. Introduction of high yielding varieties (HYVs) and intensive rice farming had led to increased use of chemical fertilizers and pesticides. Continuous and increased/indiscriminate use of sole chemical fertilizers lead to several harmful effects on the soil environment, ground and surface water, and even atmospheric pollution, reducing the productivity of the soil by affecting soil health in terms of physical, chemical and biological properties. Several long-term field experiments indicated a declining trend in grain yield under intensified rice cropping with constant and high fertilizer inputs [1]. Rice monoculture over time has clearly indicated a long-term degradation of soil resource base. Hence, enhancement and maintenance of system productivity and resource quality is essential for sustainable agriculture.

It was felt that organic farming may solve all these problems and organic farming has been considered as one of the best options for protecting/sustaining soil health, and is gaining lot of importance in present day agriculture. Significant improvements in soil physical, fertility and biological properties have been reported in several organic farming experiments [2,3]. Although grain yield under organic farming is often lower than under conventional farming, it is feasible to have increased rice yields under the former [4]. Organic agriculture enables ecosystems to better adjust to the effects of climate change, and also improves carbon sequestration potential of the soil [5]. While some research has found that organic cropping systems are less profitable than conventional systems [6], some other studies have shown that returns from organic farm management are equal to, or exceed those of conventional management. Also, there is a growing demand for organically produced foods worldwide and many international and national organizations are taking interest in organic farming research.

The complete information on organic farming in rice with regard to rice productivity, grain quality, soil health/quality and profitability in Indian soils, is very limited. Hence, the present experiment was conducted to evaluate rice productivity, grain and soil quality parameters and economics, under organic and conventional methods of rice farming systems.

Materials and Methods

Experimental site characteristics

A field experiment was conducted for five years (2004-2005 to 2009-2010), covering ten crop seasons [five wet (WS, kharif) and five dry (DS, rabi)] on a deep black clayey vertisol (Typic pellustert), at the Directorate of Rice Research farm, Hyderabad (17°19″ N latitude, 78°23″ E longitude, 542 m altitude with mean annual precipitation of 750 mm), to compare the influence of organic and conventional production systems on the productivity of super fine rice varieties, BPT 5204 (WS) and Vasumati (DS), grain quality, soil health/quality in terms of soil properties, quality indices and carbon stocks, and economic returns. The experimental soil characteristics were: slightly

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alkaline (pH 8.2); non-saline (EC 0.7l dS/m); calcareous (free $CaCO_3$ 5.01%); with CEC 44.1 C mol (p+)/kg soil and medium soil organic carbon (0.69%) content. Soil available N was low (228 kg/ha); available phosphorus was high (105 kg P_2O_5/ha), available potassium was high (530 kg K_2O/ha), and available zinc was also high (12.5 ppm). Details of soil analytical methods are explained in "Plant and soil studies". The experimental field was under rice mono cropping for the past twenty years, using inorganic fertilizers only.

Treatment details

There were two main treatments: with plant protection (PP) measures, where pesticides were used, and without plant protection (NPP) measures and four sub treatments: CON-control (no fertilizers); CF (conventional fertilizers)-100% inorganic fertilizers; OF (organic fertilizers)-100% organics and INM (integrated nutrient management)-50% inorganic fertilizers+50% organics. The design used was split-plot with three replications, plot size 80 m^2. Rice varieties with fine grain quality (BPT 5204 and Vasumati) were tested during wet and dry seasons, respectively, at 20×15 cm spacing.

The organic sources used were: green manure, dhaincha (*Sesbania aculeata*)+paddy straw during wet seasons (WS) and poultry manure+paddy straw during dry seasons (DS). The local recommended dose of inorganic fertilizers were given at the rate of 100-40-40 kg N, P_2O_5, K_2O/ha during WS and 120-40-40-10 kg N, P_2O_5, K_2O and Zn/ha during DS through urea, single super phosphate, muriate of potash and Zinc sulphate, respectively. Nitrogen was given in three equal splits at basal, maximum tillering and panicle initiation stages, while P, K and Zn were given as basal doses only. Through organics, N dose was adjusted to recommended level based on their moisture content and 'N' concentration on dry weight basis. The average nutrient content of the organic fertilizers is given in table 1. Organic fertilizers were incorporated one day before transplanting rice. Chemical plant protection measures were given to protected plots (PP) only, and irrigation and weeding operations were done according to normal practice and uniformly for all the treatments.

Plant and soil studies

Grain yields were recorded at harvest in all the ten seasons. Grain quality parameters such as physical (hulling %, milling %, head rice recovery % and L/B ratio), cooking (elongation ratio and amylose %), and nutritional quality (protein %, phosphorus % and potassium % in brown rice and polished rice), were estimated in all the seasons. Soil properties (physical, fertility and biological) were measured at the end of five years, using standard procedures. Composite soil samples were collected from 0-15 cm depth for each replicate plot, by compiling five soil cores per plot. The samples were air dried, processed using 2 mm sieve, and used for measuring soil fertility parameters such as available nitrogen by the alkaline permanganate method [7]; available phosphorus by $NaHCO_3$ extraction [8], and available potassium by neutral normal NH4OAC extraction [9]. Soil physical properties such as bulk density (core method) and penetration resistance (cone penetrometer method) were determined at the end of 5th year. Organic carbon was estimated in finely powdered (0.5 mm sieved) soil by Walkely and Black [10] method using potassium dichromate. For measuring soil respiration rate, field moist soil samples were collected from 0-15 cm depth after harvest, and the method of estimation was, CO_2 trapping in NaOH [11].

Serial number	Organic source	Number of samples	N content (%)	P content (% P_2O_5)	K content (% K_2O)
1	Paddy straw	10	0.80	0.20	1.51
2	Sesbania	10	2.80	0.22	1.25
3	Poultry manure	10	2.50	2.00	1.20

Table 1: Average nutrient content of organic fertilizers.

Soil microbiological parameters were measured at the end of the experiment using standard procedures. β-glucosidase activity was determined as described by Eivazi and Tabatabai [12]; alkaline phosphatase by the method of Tabatabai and Bremner [13]; dehydrogenase activity was measured according to the method described Tabatabai [14].

By using different approaches like nutrient index, microbial index and crop index, different production systems (CON, CF, OF and INM) were compared and soil sustainability index was calculated using a triangular approach, as per the procedure given by Batjes [15], at the end of five years. The carbon stocks in the soil were calculated following the method described by Gomez and Gomez [16], where organic carbon content was multiplied by bulk density and thickness of the particular soil layer. Profitability of the production systems was evaluated by calculating gross returns, net returns, total cost, and then benefit: cost ratio was calculated by dividing gross returns with total cost.

All the data were subjected to standard statistical analysis [17], by applying analysis of variance for split plot design. Least significant differences (LSD) were conducted at a 5% level of probability, where significance was indicated by F-test.

Results and Discussion

Grain yield trends

During wet season, grain yields with inorganics and INM were near stable (5.0-5.5 t/ha) and superior to organics by 15-20% during the first two years, which improved with organics (4.8-5.4 t/ha) in the later three years to comparable levels with inorganics and INM (Table 2). However, in the dry season, inorganics and INM (3.6-4.3 t/ha) were superior to organics (3.1-3.5 t/ha) for four consecutive years, and these three treatments were on par (4.0-4.2 t/ha) in the fifth year only. This could be due to mismatch of nutrient release from organic sources and crop demand, as influenced by seasonal conditions in the initial years, and once the soil fertility was built up sufficiently, organic system also produced equal yields as conventional system. Thus, slow and gradual release of nutrients from organics during the initial years of conversion to organic farming could not result in increased yields. But, repeated application of organics over the years may build up sufficient soil fertility by improving soil biological activity. A 20-30% less yields of crops in organic farming was reported by Yadav et al. [18]. Significant reduction in rice yield when 50% chemical fertilizers were substituted with organics was also reported by Sharma and Singh [19]. The recession in the crop yields during initial phase of transition from conventional to organic agriculture and recovery in yields after 2-3 years was reported by Maeder et al. [20]. Yield loss of organically grown rice is reported to the tune of 24% [21], though organic farming system showed efficient resource utilization. Increased growth and yield of rice with continuous organic farming in comparison with conventional farming was also observed in Japan, where Urkurkar et al. [22] found that the growth and yield of rice increased. A similar result of gradual increase in rice grain yield with the use of organics over a period of time was also observed [23]. Unfertilized control treatment recoded the lowest grain yields throughout the experiment.

Yield differences, with and without plant protection measures, were only marginal during most part of the study due to very low pest pressure (below threshold levels). Lower grain yields in dry season compared to wet season could be ascribed to the varietal difference,

Year	*Kharif (WS)*		*Rabi (DS)*		*Kharif (WS)*				*Rabi (DS)*			
	NPP	PP	NPP	PP	Cont.	Inorg.	Org.	INM	Cont.	Inorg.	Org.	INM
2004-05	4.50[a]	4.80[a]	3.38[a]	3.43[a]	3.45[c]	5.47[a]	4.68[b]	5.00[ab]	2.03[c]	3.79[a]	3.52[b]	4.28[a]
2005-06	4.31[b]	4.91[a]	3.08[a]	3.26[a]	3.36[c]	5.35[a]	4.59[b]	5.15[a]	2.17[c]	3.74[a]	3.10[b]	3.62[a]
2006-07	4.28[b]	4.84[a]	3.00[a]	3.60[a]	3.13[b]	5.20[a]	4.87[a]	5.03[a]	2.48[c]	3.81[a]	3.14[b]	3.77[a]
2008-09	4.49[a]	5.01[a]	3.27[a]	3.17[a]	3.33[b]	5.33[a]	5.23[a]	5.12[a]	2.01[c]	3.76[a]	3.27[b]	3.86[a]
2009-10	4.70[a]	4.73[a]	3.57[a]	3.63[a]	3.19[b]	5.23[a]	5.36[a]	5.08[a]	2.12[b]	4.18[a]	3.98[a]	4.13[a]

Table 2: Grain yield (t/ha) as influenced by nutrient sources.

	Physical quality								Cooking quality			
Treatments	Hulling %		Milling%		Head rice recovery %		L/B ratio		Elongation ratio		Amylose %	
	DS	**WS**	**DS**	**WS**	**DS**	**WS**	**DS**	**WS**	**DS**	**WS**	**DS**	**WS**
Control	77	76	66	63	22	55	4.23	2.65	1.99	1.72	25.8	23.7
Inorganics	79	77	68	64	28	51	4.26	2.68	2.05	1.69	25.7	24.2
Organics	77	77	66	64	25	56	4.22	2.66	2.09	1.76	26.0	24.0
INM	78	77	68	64	32	55	4.24	2.63	2.05	1.78	25.7	24.0
LSD (0.05%)	NS	NS	NS	NS	NS	NS	NS	NS	0.039	0.041	NS	NS

Table 3: Grain quality parameters as influenced by nutrient sources (5[th] year).

Treatments	Protein %				Phosphorus (g/kg)				Potassium (g/kg)			
	BR		WR		BR		WR		BR		WR	
	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS
Control	8.02	7.66	7.46	7.74	2.0	2.8	1.1	1.1	1.9	2.3	1.1	1.1
Inorganics	8.55	8.31	8.16	7.56	1.7	3.2	1.0	1.0	1.7	2.3	1.0	1.0
Organics	8.58	8.71	8.14	7.76	2.0	3.3	1.1	1.2	1.9	2.5	1.1	1.2
INM	8.57	8.16	8.20	7.8	1.8	3.1	1.0	1.3	1.6	2.3	1.0	1.2
LSD (0.05%)	NS	NS	NS	NS	0.25	0.32	0.08	NS	0.11	0.15	NS	NS

BR-Brown rice; WR- white rice; DS- Dry season; WS-Wet season

Table 4: Grain quality (nutritional) parameters as influenced by nutrient sources (5[th] year).

Trts.	**Physical**		**Fertility**				**Biological**			
	B.D Mg/m3	P.R kg/cm2	SOC %	N kg/ha	P2O5 kg/ha	K2O kg/ha	SR	B-g	A.P	D.H
Control	1.40	10.2	0.59	213	92	528	0.158	95	425	1210
Inorganics	1.48	11.8	0.64	225	167	548	0.173	140	458	1352
Organic	1.30	7.7	1.01	256	184	592	0.208	162	563	1623
INM	1.32	9.5	0.91	227	172	545	0.183	145	488	1501
LSD (0.05%)	**0.07**	**1.45**	**0.12**	**NS**	**14**	**41**	**0.024**	**20**	**77**	**32**

B.D-Bulk density; P.R-Penetration resistance; SOC-Soil organic carbon; SR-Soil respiration in mg CO_2/24 h/g; Bg-Beta glucosidase, and AP-Alkaline phosphatase in μg p-nitrophenol/g/h; DH-dehydrogenase in μg Triphenyl formazon/g/24h

Table 5: Soil quality parameters after five years under organic and conventional systems.

where the Vasumati variety used in the DS was aromatic, and in general, the yield levels of aromatic rice are low.

Grain quality parameters

Grain quality parameters recorded at the end of five years were presented here. Since the plant protection treatments did not influence these properties significantly, the values of sub-treatments only are discussed here by giving the mean values of PP and NPP. Most of the grain quality parameters were not influenced even after five years of study, though moderate improvement in nutritional quality was recorded with organics, especially in brown rice over inorganics, and polishing reduced the quality improvement. Physical grain quality parameters-milling %, hulling %, head rice recovery (HRR), length/breadth (L/B) ratio; cooking quality parameters-amylose content and elongation ratio were not influenced by the nutrient sources even after 5 years of study. However, in the fifth year, there was an improvement in HRR by 9.5%, with organics over inorganics (Table 3). Similarly, there was an improvement in elongation ratio by 4.1% with organics over inorganics. Whereas, moderate improvement in nutritional quality parameters such as protein, phosphorus and potassium contents was recorded with organics, compared to inorganics (Table 4), and brown rice recorded higher values (by 5-16%) than polished rice (by 1-6%). A significant improvement in nutritional quality (Fe and Mn), with combined application of 2 or more organic sources and with 3 or 4 organic sources, in case of Zn and Cu contents in organic farming with Pusa basmati 1 scented rice variety, was reported by Saha et al. [24], while sole application of any organic source (Azolla, BGA, FYM and vermi compost) did not increase the nutritional quality. In another experiment on organic farming, the grain quality parameters were studied, and it was reported that organic nutrient sources can perform comparatively well as regards chemical and physico-chemical properties and cooking quality of rice, if not better in some parameters than inorganic fertilization [25]. Improvement in HRR, kernel length, breadth and L/B ratio after cooking with the application of organic sources alone was also reported [26].

Field experiments conducted in Annamalai University in India with rice clearly indicated a positive approach towards organic farming in attaining premium quality produce, with higher grain yield. Quality characters *viz* milling recovery, head rice percentage and protein percentage were significantly higher with organic sources [27]; whereas, there are enough indications that organically grown products are superior in various essential minerals and vitamins, and have lower toxic components such as nitrates and heavy metals [28].

Soil quality parameters

Changes in soil quality parameters were monitored at the end of every year, and results at the end of fifth year are presented in (Table 5). Since the plant protection treatments did not influence these properties significantly, the values of sub-treatments only are discussed here by giving the mean values of PP and NPP. There was a significant improvement in soil physical (bulk density and penetration resistance), fertility (organic carbon and available N, P and K), and biological properties (soil respiration and enzyme activities *viz.* glucosidase, phosphatase and dehydrogenase), with organics compared to inorganic fertilizers. Compared to inorganics, there was an increase in soil organic carbon (SOC), available N, P and K by 59-65, 3-10, 10-27 and 8-25% with organics, respectively, at the end of five years. Paddy straw being rich in potassium and poultry manure with high phosphorus content, are the possible factors responsible for the observed increase in soil P and K values in treatments where these two organic sources were used. A further reason for the SOC increase may be the slow decomposition of applied and native soil organic matter due to prevailing anoxic conditions and formation of difficultly decomposable SOC under rice-rice system [29]. Comparable increases in organic carbon, available N, P and K through addition of organic materials was also reported [3,30]. Superior soil fertility status on organic farms compared to soils fertilized with chemical fertilizers was also reported [20].

Enzyme activities in soil were also influenced by different treatments. Enzymes catalyse the biochemical reactions involved in nutrient cycling in soils. β-glucosidase, involved in carbon cycling; alkaline phosphatase, that plays a major role in the mineralization of organic phosphorus substrates and dehydrogenase, which is an indicator of total microbial activity, were significantly higher with organics compared to inorganics. Increase in extra cellular enzyme activities (alkaline phosphatase, protease, and β-glucosidase) has been reported to be higher in soils under organic management than under conventional management, because the addition of organic amendments activates microorganisms to produce enzymes [31]. Soil respiration rate, another important indicator of soil biological activity, was also significantly higher with organics over inorganics. Addition of organic sources provide a stable supply of C and energy for micro-organisms and cause an increase in the microbial biomass pool, thereby increasing soil respiration rate. Several authors have also observed higher respiration rates in organically managed soils than in conventionally managed soils [3], due to additional carbon inputs in organically managed soils. Favourable improvement in soil physical, fertility and biological properties was reported in many organic farming experiments [3].

Trts.	Carbon stocks (t/ha)		Carbon sequestration rate (t/ha/year)	
	Wet season	Dry season	Wet season	Dry season
Control	12.04	11.18	-0.53	-0.70
Inorganics	13.63	13.05	-0.21	-0.33
Organic	19.54	17.55	0.97	0.57
INM	18.29	15.64	0.71	0.19
Initial value	**14.70**			

Table 6: Organic carbon stocks and sequestration rate after 5 years.

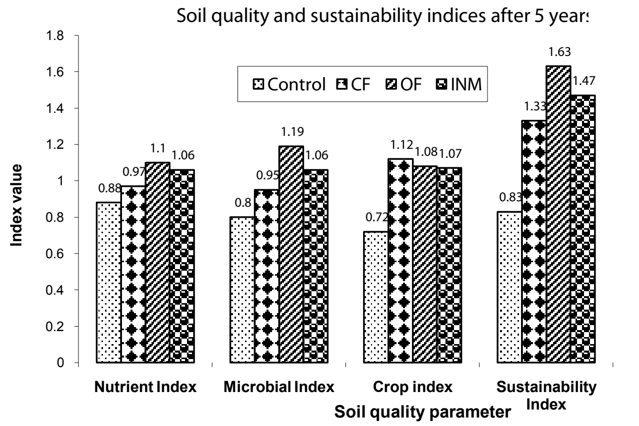

Figure 1: Soil quality and sustainability indices as influenced by different nutrient management practices.

Treatments	Year 1 (2004-05 [kharif+rabi])			
	Total cost (Rs.)	Gross returns (Rs.)	Net returns (Rs.)	B:C ratio
Control	25,420	28,496	3,076	1.12:1
Inorganics	35,045	48,152	13,107	1.37:1
Organics	38,950	42,640	3,690	1.09: 1
INM	36,997	48,256	11,259	1.30:1
	Year 5 (2009-10 [kharif+rabi])			
Control	35,850	44,000	8,150	1.23:1
Inorganics	50,995	89,395	38,400	1.75:1
Organics	58,600	1,16,750	53,480	1.99:1
INM	53,750	87,495	33,745	1.63:1

Table 7: Cost of cultivation and net returns/ha/annum under different production systems.

Soil quality, as measured by different indices, *viz.* nutrient index (NI), microbial index (MI), and crop index (CI) indicated maximum nutrient (1.10) and microbial (1.19) indices, with organics and inorganics recorded 0.97 & 0.95 NI & MI values, respectively (Figure 1), whereas, the crop index was maximum with inorganics (1.12), compared to organics (1.08). The sustainability index (SI) of the soil system, measured from above three indices was maximum with organics (1.63), and inorganics recorded 1.33, which was just above the minimum sustainability index of 1.30. Similarly, it was reported that application of rice straw compost alone for 4 years gave a sustainability index of 1.69, compared to chemical fertilizer system that recorded sustainability index of 1.07 in a rice-wheat cropping system [15].

The soil organic carbon (SOC) stocks were higher with organics (19.5 and 17.5 t/ha), compared to conventional system (13.6 and 13.0 t/ha), during wet and dry seasons, respectively, after 5 years of study (Table 6). The carbon sequestration rate was also positive with organics (0.97 and 0.57 t/ha/yr during wet and dry seasons, respectively), compared to conventional system that recorded negative SOC sequestration rate (-0.21 and -0.33 t/ha/yr during wet and dry seasons, respectively). INM recorded higher values than inorganics, and control recorded much lower values than all the treatments in both the seasons. Higher carbon stocks and positive carbon sequestration rate with 100% organics compared to inorganics, and negative sequestration rate in control treatment under rainfed rice production system was also reported [32].

Economics of the study

With regard to economics, total cost of cultivation, gross returns, net returns and benefit: cost ratio were calculated at the end of all five years, and the results pertaining to first and fifth years of study were presented in (Table 7). The total cost of production was high with organics in all the 5 years of study. Though gross returns, net returns and benefit/cost (B:C) ratio were higher in inorganic production system in the first year (with 1.37 and 1.09 B:C ratio in inorganic and organic systems, respectively), organic system showed its superiority in the fifth year by fetching higher returns (with 1.75 and 1.99 B:C ratio in inorganic and organic systems, respectively). The benefit: cost ratio under INM treatment was almost similar to inorganics in all the years, and control treatment recorded the least B: C ratio. The production costs also can be reduced in due course by proper utilization of on-farm residues and waste materials.

The Lowell farms of Texas recorded their organic rice yield at 50-60% of conventional yields, but it commanded a price two to three times higher than that of conventionally grown rice [33]. In India also, though the yield levels of rice under conventional type of farming would have been more, the yield per rupee invested could have been more under organic farming [34]. The economic comparison made during 1991-2001 (without price premium for organic) in organic corn-soybean rotation with conventional corn-soybean system revealed that the net returns for both systems were similar. Over 10 year period, organic corn was 25% more profitable than conventional corn because organic corn yields were only 3% less, while costs were 15% less than conventional corn [27]. It was also reported that organic rice farming is more profitable and cost effective with higher productivity than conventional rice farming.

Conclusions

From the present research study at the Directorate of Rice Research, it can be concluded that organic system of rice production needs more than two years period to stabilize rice productivity, and bring about perceptible improvement in soil quality, sustainability indices and economic returns under intensive, irrigated rice-rice system in vertisols of tropical climate, depending on the season. Organic rice production can be sustainable and economical/remunerative over a period of time, once the soil fertility is built up due to continuous use of organic nutrient sources that release the nutrients to the plant in a balanced way, for a longer period. Hence, using easily available local natural resources, organic farming can be practiced with a view to protect/preserve/safe guard our own natural resources and environment for a fertile soil, healthy crop and quality food, and let our future generations enjoy the benefits of non-chemical agriculture. Given the same profitability, organic farming is more advantageous than conventional farming, considering its contribution to health, environment, and sustainability.

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