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Edited by

S. S. Acharya

Surjit Singh

Vidya Sagar

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Agricultural Production System and Environmental Sustainability

B.C. Barah

The total agricultural production in India at the time of independence was about 50.82 million tonnes. But, on account of several policy measures including the expansion of cropped area from 99 million hectares in 1950-51 to 118 million hectares in 1964-65, the agricultural production increased to the tune of 89.64 million tonnes. Subsequently, the area under foodgrains touched about 124 million hectares in 1997-97. More importantly, the launching of the Green Revolution, along with policy support measures such as irrigation, fertiliser, plant protection measures, intensive research and development initiatives, gave a boost to production to 199.32 million tonnes in 1997. During the period the crop productivity improved from 553 kilogram per hectare in 1951 to 1,601 kilogram per hectare in 1997. The per capita availability of foodgrains also improves substantially. The rapid increase in production also brought about a change in the composition of food basket. In the per capita food configuration, wheat gained substantially, whereas gram, pulses and other cereals lost their previous position (Table 1).

Table 1 *Per capita availability of foodgrains in India (kg/year)*

Year	*Rice*	*Wheat*	*Other cereals*	*Cereals*	*Gram*	*Pulses*	*Foodgrains*
1951	158.9	65.7	109.6	334.2	22.5	60.7	394.9
1964	201.4	90.1	109.5	401.0	20.3	51.0	452.0
1980	166.1	126.8	86.6	379.5	10.7	30.9	410.4
1990	212.2	132.6	86.8	451.1	13.4	41.9	493.4

The coarse cereals lost rapidly in favour of rice-wheat system and other short-run remunerative systems. The Green Revolution ushered in the mid-1960s has made tremendous impact on the availability of superior cereals such as rice and wheat, but ignored the several other commodities as well. The cereal-cereal rotations became more prominent and the ecologically beneficial cereal-pulse rotations declined drastically. This development raises doubts not only on the adequacy of the nutritional programmes, but also several other ecological questions.

While the goal of feeding hungry millions has been achieved to an extent by increasing production but the appropriate policy initiative to tackle the problem of feeding hungry plants has not received desired attention. The growth has become a single-tracked production-oriented approach, which marginalised the crucial question on sustainability. The externality of intensive use of external inputs is immense, which must be studied. What kind of sustainable agricultural production system should we promote -- whether modern input-intensive or traditional low input, stable but low unit productivity system or a mixed of both. The transition from traditional system to modern methods revolutionised the food production scenario but the sustainability properties are ignored in the newer methods.

Evolution of Alternative Technology

Mode of production		*Special characteristics*
Inherited: Traditional Agriculture	→	Non-degrading, stability at low level, utilises low external inputs and more local inputs. But amenable to acute poverty
Developed: Modern agriculture	→	High and fast yielding, more promising returns to investment but intensive external input using, resulted in resource depletion. It affects long run sustainability
Required: Sustainable agricultural production system	Should satisfy	Yields more and sustained net return, low production cost, conserve natural resources and preserve biodiversity

The traditional agricultural methods were non-degrading, low external input and more local input using and stable but their productivity is low. The modern system is high and fast yielding, promising return to investment and uses intensive external inputs. But it is highly resource degrading affecting the long-term stability. Therefore, a desirable agricultural system is one, which yields more, sustains net return, conserves natural resources such as land and water, and preserves biodiversity. Else, the externality of input-intensive modern method endangers the sustainability of food security. It is, thus, essential to understand the long-term implications of this innovative system of crop production on degradation. In this context, the long-term fertiliser experimental trials on rice-wheat system are chosen to study the change in fertiliser responses and address the complex problems of unsustainability.

These questions are critical as the declining responses to the factors of production in the recent times, as compared to the earlier period, have been threatening long-term food security. It implies that more additional of external inputs are necessary to obtain constant level of yield, resulting in adverse impact on net farm income. Ensuring sustainability requires in-depth study on cause and effect relationship and an objective evaluation of alternative options. It necessitates more efficient economic analysis of scientifically designed micro-level production system for enhanced value addition and instrument for agricultural policy (Abraham and Rao, 1966; Heady and Dillon, 1961; Anderson, 1968). More efforts are needed to integrate socio economic dimensions to modern agricultural technology by using on-station data on experimental trials.

In view of growing concern for intensive use of chemical fertiliser in crop production in the recent period, the studies in fertiliser use efficiency assume crucial importance. Most studies in the past looked at issues such as fertiliser use, geographical spread of fertiliser consumption and fertiliser response at on-station as well on farmers' field (Kumar, 1995; Gandhi et al., 1995; Desai and Vaidyanathan, 1995). The level of adoption, nature of fertilisation, extent of area, rate of fertilisation, etc., are some of the questions examined in these studies. But, the long-term impact of continuous and intensive modern technology on sustainability as well as on the health of the natural resource, has not been not examined adequately.

The input intensive agriculture immensely contributed towards the goal of increased food production, but has by passed the issues on sustainability and consequent deceleration in agriculture production. Hence, there is need to examine the causal relationship of intensive external input use in agriculture and environmental degradation. This paper attempts to study indepth the trends in response to on-station fertiliser treatments and to test the hypothesis that indiscriminate use of external inputs endangers environmental sustainability. The following questions are raised in this connection: What is the long-term impact of use of external input on sustainable agriculture as well as on natural resources? Or alternatively, could the productivity be sustained through intensive modern methods in agriculture? The paper also endeavours to analyse the trends in terms of-station crop productivity, develop efficient choice criteria of alternative technologies and indicators of long-term sustainability of cropping system. An analysis of rice-wheat system is purposively chosen for this study, as it contributes significantly to, and is in the forefront of, Indian agriculture.

Rice-Wheat System

Studies on fertiliser responses to rice-wheat system assume importance because rice and wheat together cover about 55 percent of total cropped area and contribute about 75 percent of total foodgrain production. But, despite the importance in increased food economy, the system is highly vulnerable to environmental degradation.[1] Thus, the attempt is made to examine the optimal fertiliser use efficiency and sustainability of the system.

The area under the sequential rotation is expanding rapidly in recent times due to its popularity among the farmers. The rice-wheat system although a major player, its externality of continuous cropping resulted in resource degradation and endangered food security (Joshi *et al.*, 1998). The productivity of rice and wheat is already beginning to decline rapidly, signalling a disturbing trend of the long-term food production. The rate of productivity growth has relatively been modest and stagnated in the recent period. It is pertinent and timely to address the sustainability question, which is required to be tackled jointly by the biological scientists, social scientists and policy makers as a strategy to arrest unsustainability of growth of the rice-wheat system.

The productivity trend in long-term fertiliser experiments is examined using appropriate trend equations. The incremental gain in net return is calculated to measure the partial factor productivity of fertiliser. The gain in net return over the control level is considered advantageous as it combines the biological yield and market prices. The net return acts as a bridge between the socio-economic consideration and the agronomic decision criteria. The alternative technological options are ranked on the basis of stability and adaptability parameters and compared with the ranking based on biological yield characteristics. The physical and biological characteristics are used to build the indicator of sustainability The panel regression technique is particularly useful to sharpen the choice of the options. A unified socio-economic approach onto biological experimentation provides a realistic approach to understand the actual behavioural pattern of sustained agricultural production system.

Long-term Experiments

Long-term experiments are those, which are continued on *the same set of plots* over a series of years with a pre-planned sequence of treatments or crop or both (Panse *et al.*,1964). It aims at the study of long-term effect of given treatments and crops on soil fertility and on economic returns.

The on-station long-term fertiliser experimentations are designed to accomplish the following objectives:

(a) to develop suitable nutrient supply and management system and to study the long term effect of fertiliser in combination with organic manure on the productivity of cereal based crop sequence and on soil health; and

(b) to improve fertiliser use efficiency in the cropping system.

The micro-level long-term experimental trials have been designed and conducted on permanent plots at multi-locations and multi-period under the All Indian Coordinated Agronomic Research Project of the Indian Council of Agricultural Research. The Project Directorate of Cropping System Research (PDCSR) at Modipuram monitors the agronomic trials at large number of experimental stations.

The muliti-location experiments on integrated nutrient supply in cereal-based crop sequences and on long range effects of continuous cropping and manuring look at the soil fertility and yield stability on permanent plot experiments. The permanent plots long-term fertiliser trials data are collected from 11 centres in four agro-ecological regions, viz; semi-arid, sub-humid, humid and coastal ecosystems. It covers physical data of the experiments for over ten years from 1985-86 to 1995-96. The unique and scientifically designed on-station experimental trials provide reliable and accurate parameters of fertiliser response behaviour. The spatio-temporal data on fertiliser experimental trials are analysed by using socio-economic methodology and derive lessons for future policy framework. The relevant data on several physical and climatic variables will also be used in the analysis.

Experimental Treatments

Table 2 enlists treatments of various mix of organic and inorganic fertilisers (numbered serially from 1 to 12; first one being the control treatment and the last as the farmers' practices). The well-laid experiments using randomised block design are conducted with these treatments in four replicated plots in each of the stations. Since the analysis deals with rice-wheat system, the treatments represent sequential application of fertiliser doses in the order of kharif and rabi seasons.

Table 2 *Treatment combination for on-station long term fertiliser trials*

SNo.	*Treatments*		*Kharif (Rice)*	*Rabi (Wheat)*
Tr1	NPK0	Control	Control (zero fertiliser)	Control
Tr2	NPK1	Chemicals	50%NPK	50%NPK
Tr3	NPK2	Chemicals	50%NPK	100%NPK
Tr4	NPK3	Chemicals	75%NPK	75%NPK
Tr5	NPK4	Chemicals	100%NPK	100%NPK
Tr6	NPK1FYM1	Organo-chemical	50%NPK+50% FYM	100%NPK
Tr7	NPK2FYM2	Organo-chemical	75%NPK+25% FYM	75%NPK
Tr8	NPK1CR1	Organo-chemical	50%NPK+50%CR	100%NPK
Tr9	NPK2CR2	Organo-chemical	75%NPK+25% CR	75%NPK
Tr10	NPK1GM1	Organo-chemical	50%NPK+50% GM	100%NPK
Tr11	NPK2GM2	Organo-chemical	75%NPK+25% GM	75%NPK
Tr12	Farmers' practices		Farmers' practices	

Note: NPK denotes recommended fertiliser dose(RFD) of nitrogen, phosphorous and potash.
FYM = FarmYard Manure, CR = Crop residues (straw), GM = Green manure

Long-term Fertiliser Response

Table 3 shows that the average yield of paddy as well as wheat is the lowest in Navasari as compared to other locations. It varies from 14.7 q/ha for control treatment to 33.7 q/ha for treatment NPK4 for paddy. Barring the yield of control treatment, the yields for other treatments are found to be highest in Ludhiana. In case of wheat also, the yield for the treatments NPK1, NPK3 and NPK1FYM1 was highest in Ludhiana, for treatments NPK4, NPK2FYM2, NPK1CR1 and NPK2CR2 in Kanpur and for control treatment and NPK2 in Pantnagar. The control yield of 7.1 q/ha is the lowest at Palampur, followed by Kalyani (7.6 q/ha), the highest yield being 15.5 q/ha for control treatment in Pantnagar. The response to the treatment NPK1FYM1 is the highest at 47.2 q/ha in Ludhiana, and for the treatment NPK1GM1 in Kanpur is 47.5 q/ha. The comparison of treatment performances across locations shows that the gain in yield due to fertilisation is over 100 percent of the control yield for all the treatments in paddy as well as wheat. However, the gain varies from treatment to treatment. The variation of yield gain arises primarily due to local factors other than fertilisation. The differential responses to treatments depend on how the physical and environmental conditions of the locality react to external inputs.

Table 3 *Mean of experimental yield of paddy for different fertiliser treatment*

(q/ha)

Treatments	*Navasari*	*Faizabad*	*Jabalpur*	*Kalyani*	*Kanpur*	*Pantnagar*	*Sabour*	*Ludhiana*
Control	14.7	19.1	24.1	14.6	15.7	30.3	16.2	20.3
NPK 1	24.4	32.8	33.0	25.8	29.9	38.0	28.8	42.4
NPK2	25.8	34.3	36.7	26.1	31.6	37.3	29.4	45.9
NPK3	28.7	40.5	46.7	30.7	35.2	40.9	34.4	54.9
NPK4	33.7	43.8	46.8	33.1	40.2	46.6	41.7	64.9
NPK1FYM1	29.5	42.0	43.7	33.9	34.9	40.6	39.0	59.5
NPK2FYM2	31.0	46.2	48.2	36.5	37.3	41.5	42.2	61.6
NPK1CR1	32.5	40.8	38.7	33.2	33.3	40.5	37.4	53.7
NPK2CR2	31.8	40.6	40.5	34.2	35.5	42.4	39.1	60.4
NPK1GM1	32.7	41.9	48.9	36.6	35.9	44.4	37.3	65.2
NPK2GM2	33.2	42.6	49.1	37.4	39.1	46.0	39.0	66.7
F/P	20.5	31.1	29.0	24.4	32.6	44.4	29.4	24.7

As many as 21 cases show significant improvement in yield of paddy in the range of 50-100 percent, none in the 50 percent class and the rest in the 100 percent class. Barring Navasari, the improvement in yield in most of the locations exceeds by over 100 percent of control level for wheat and there are only seven cases in the 50-100 percent category (table 4). Being situated in the coastal ecosystem, the crop yield is severely constrained in Navasari. The yield for other treatments in Navasari is also lowest and in Ludhiana is the highest. This indicates differential locational advantages to minimum potential yield.

Table 4 *Mean experimental yield of wheat for different treatmens*

(q/ha)

Treatment	*Faizabad*	*Jabalpur*	*Kalyani*	*Kanpur*	*Navasari*	*Pantnagar*	*Sabour*	*Ludhina*	*Palampur*	*Raipur*	*Varanasi*
Control	8.2	10.2	7.6	12.0	10.5	15.5	9.0	12.7	7.1	12.5	9.0
NPK 1	24.7	18.1	15.7	29.4	16.8	28.4	18.1	31.7	15.9	20.3	18.1
NPK2	33.7	26.3	26.2	37.7	19.1	36.1	29.1	43.2	21.2	26.0	29.1
NPK3	30.3	25.3	24.7	35.4	18.9	32.1	26.7	38.5	20.3	25.6	26.7
NPK4	34.6	28.6	25.5	45.4	21.5	38.8	30.7	44.4	24.6	27.7	30.7
NPK1FYM1	36.2	26.8	29.3	46.0	20.3	37.4	33.0	47.2	27.5	29.0	33.0
NPK2FYM2	30.7	24.6	26.3	43.2	18.9	35.1	29.2	43.0	21.8	28.3	29.2
NPK1CR1	32.9	27.1	30.7	45.4	20.1	34.9	30.4	43.6	22.0	29.0	30.4
NPK2CR2	31.0	22.8	25.9	42.5	17.4	34.3	28.5	38.8	20.9	28.2	28.5
NPK1GM1	33.3	27.0	29.7	47.5	19.9	38.4	29.6	43.0	20.3	30.5	29.6
NPK2GM2	30.7	24.5	24.8	45.4	17.6	35.4	29.2	39.1	20.9	29.9	29.2
F/P	22.1	18.2	21.5	32.7	17.8	37.2	18.9	24.3	16.2	25.3	18.9

Wheat follows paddy in the experimental plot and thus the yield of paddy as well as wheat is influenced by their joint effect. The functional relationship of yield response can be written as:

$Y_{paddy} = f(NPK, Y_{wheat})$ and $Y_{wheat} = f(NPK, Y_{paddy})$

The treatment NPK1 doubles the yield of paddy in 44 percent of the stations and the farmer practices in six out of 12 experimental stations. The yield of paddy is more evenly distributed in all the yield improvement class intervals across the locations with the highest performing treatment being the treatment NPK1GM1. The response to organo-chemical, i.e., treatments 6 to 11 is higher than that of the pure chemical fertiliser besides these treatments help upkeep of the soil health. These treatments also sustain the soil quality, particularly under anaerobic condition (Singh *et al.*, 1991).

Economics of Organo-Chemical-Fertiliser Treatments

The chemical fertiliser increases the productivity of paddy and wheat significantly. But, indiscriminate use of agro-chemicals resulted in accumulation of nutrients in the soil, which affect crop productivity adversely. The excessive build up of the micro-nutrients distorts the proper balance and the soil becomes sensitive to crop yield. Thus, appropriate policy intervention is necessary to ensure minimum balance of required nutrients in the soil to sustain yield. The depletion of soil nutrients due to the application of agro-chemicals perpetuates the application of extra dose of external artificial inputs to maintain minimum quantity of soil nutrients. Even if the external inputs such as chemical fertilisers stabilise the crop yield whereby the adopter farmers reap substantial short-term gains but it is associated with a heavy cost of deleterious soil health in the long run. The soil fertility experiment shows that at the beginning of crop cycle of long-term trials, the nutrients improve the yield and maintain soil balance within the range of carrying capacity. But, on continuous cropping, these nutrients gradually get depleted, which incur loss of crop yield. The fertiliser treatment like any other factors of production is subjected to diminishing marginal return to scale. Yadav (1998) has shown that continuous cropping of rice-wheat system depletes soil micro-nutrients and reduces the partial factor productivity of fertiliser treatment to the extent of – 32 percent for control and – 40 percent for full dose of recommended fertiliser in Pantnagar. The results of the on-station experiment on fertiliser treatments show that the response to fertiliser improves in the initial period but declines in the long run. Since, the yield stability is the primary goal of the on-station fertiliser trials, the decline of long-term yield is a matter of concern (table 5). It is also observed that the decline of yield (indicated as bold negative figures) is more widespread than the gains. The frequency distribution of decline in yield is more skewed in favour of pure chemical fertiliser treatment, favouring the hypothesis of productivity decline.

The loss of yield due to combination treatments is milder and also occurs in fewer stations (lowest being in two stations for NPK1FYM1). The decline in yield response to pure chemical fertilisers as a group (treatments 2-5) is more than that of

Table 5 *Frequency of decline in crop yield for each of the treatments over locations*

Treatment	*Yield of Paddy*		*Yield of Wheat*	
	Decline	*No decline*	*Declined*	*No decline*
Control	5 stations	5	7 stations	3
NPK 1	5	5	4	6
NPK2	5	4	5	5
NPK3	3	7	5	5
NPK4	4	6	4	6
NPK1FYM1	2	8	5	5
NPK2FYM2	3	7	3	7
NPK1CR1	3	7	6	4
NPK2CR2	3	7	3	7
NPK1GM1	3	7	4	6
NPK2GM2	3	7	4	6
Farmer practice	2	8	2	8

the organo-chemical treatment group (treatments 6-11). More than 50 percent of the stations shows yield decline in paddy as well as wheat in case of pure chemical fertiliser treatments. On the contrary, eight out of ten stations show yield improvement for the organo-chemical treatments. It can thus be inferred that the organo-chemical treatments are more yield sustaining as against the pure chemicals. The analysis of micro-level experimental data confirms that the indiscriminate application of pure chemical fertiliser without the use of organic fertilisers, potentially endangers food production besides degrading the land resources. Thus, the judicious use of external inputs and choice of optimal input mix is the kingpin to negate the environmental externality and improve the overall efficiency of the system. An effective synergy among biological scientists and social scientists is thus necessitated in problem solving on the sphere of technology development and its dissemination.

Impact of Sequential Cropping on Land Quality

Table 6 compares the initial values to the nutrient status after the application of treatments at different locations. It shows that the pure fertilisers are more nutrient depleting than the combination fertilisers. The organo-chemical treatment potentially replenish the depleted nutrients (figures highlighted in the Table 5) and help maintain a desired level of soil balance. The loss of nutrient as indicated by downward arrow is more frequent for control, NPK1 and NPK4 than the organo-chemical treatments. Paroda *et al.* (1994) also observed that the application of green manure (sesbania) increases the organic carbon (OC%) in soil after rice cultivation from 0.29 percent (initial) to 0.45 percent at the experimental stations. The organic carbon increases from 0.38 percent on removal to 0.47 on incorporation of crop residues (wheat straw in rice field). The multi-location analysis of the change of soil status over the years reconfirms these long-run deleterious effects on productivity due to indiscriminate application of chemical fertilisers as well as on soil health. To mitigate the adverse effect, more and more additional kilogram of fertilisers are needed atleast to maintain the constant output. Therefore, in the long run, the economic losses may overtake the increase in productivity, if the due care is not taken in the upkeep of the soil health.

Table 6 *Depletion of soil nutrients for selected treatments due to continuous cropping of rice-wheat sequence*

Station	*year*	*Initial values*	*Control*	*NPK1*	*NPK4*	*NPK1FYM1*	*NPK1CR1*	*NPK1GM1*
			No fertiliser	*NPK 50%*	*NPK 100%*	*NPK+ FYM*	*NPK+ CR*	*NPK+ GM*
Organic Carbon (%)								
Navasari	1992-93	0.62	0.43	0.44	0.44	0.45	0.45	0.44
Sabour	1993-94	0.44	0.3	0.3	0.4	0.5	0.5	0.5
Palampur	1993-94	0.6	0.6	0.6	0.7	0.7	0.6	0.7
Kanpur	1993-94	0.4	0.1	0.1	0.3	0.2	0.2	0.3
Faizabad	1993-94	0.4	0.2	0.4	0.4	0.5	0.5	0.5
Nitrogen (kg/ha)								
Navasari	1992-93	286	256	255	270	248	239	253
Palampur	1993-94	675	477	702	752	671	665	727
Faizabad	1993-94	102	78	90	114	127	117	122
Phosphorous (kg/ha)								
Navasari	1992-93	42	22	21.5	22.5	23	23.5	22.5
Sabour	1993-94	21.5	5	6	10	11	10	10
Palampur	1993-94	21.9	27	41	48	43	42	41
Kanpur	1993-94	16	8	10	22	18	17	21
Faizabad	1993-94	14	8	13	20	21	17	22
Potash(kg/ha)								
Navasari	1992-93	336	204	190.5	167	209	209	192
Sabour	1993-94	165	108	117	138	152	145	136
Palampur	1993-94	221	247	258	219	241	219	247
Kanpur	1993-94	182	115	122	155	169	191	179
Faizabad	1993-94	355	277	292	290	305	324	298

Degradation of Soil Quality

Table 7 also shows that the depletion of organic carbon content nitrogen content, phosphorous (p) content and potash content is occurring more frequently than the accumulation across the stations and over time. The organic carbon depleted by as much as 50 percent to 75 percent of the initial values in majority of the station. The organic carbon content of soil has improved the initial value in a couple of stations. It emphasises that regionally differentiated fertiliser policy must include the local conditions to sustain soil quality. The behaviour of nitrogen-content in soil is similar to that of organic carbon content. The FYM + NPK and GM + NPK contribute more towards the nitrogen balance of soil as compared to the pure chemicals. The accumulation of the nutrient ranges from 52 percent to 56 percent above the level of control treatment.

Table 7 *Integrated sustainability indicators*

Location	*Indicator*	*NPK 100%*	*NPK1FYM1*	*NPK1CR1*	*Remark*
Faizabad	FDR	+ (R3)	+(R1)	+(R2)	Mixture of NPK and FYM and crop residues are more sustainable than pure chemical fertilisers
	Std (FDR)	(R1)	(R3)	(R2)	
	CARG	(R3)	(R1)	(R2)	
	OC%	Unchanged	Improved	Improved	
	N	impr(12%)	Impr(25%)	Impr(15%)	
	P	impr(42%)	Impr(50%)	Impr(21%)	
	K	depl(18%)	Depl(9%)	Depl(8%)	
	FDY	+(R2)	+(R1)	+(R3)	
	Std(FDY)	(R1)	(R3)	(R2)	
Sustainability Index					
Faizabad	10.36	11.85	13.56		
Ludhiana	3.0	5.0	4.0		
Navasari	0.65	0.40	3.13		

Note: Bracketed figures with R prefix denoted rank of the treatments, percentages denote percent of improvement or depletion of the soil nutrients. Alternatively appropriate binary scales can also used to denote the soil status.

Phosphorous(p) Content

The mixed fertilisers improves the phosphorous content of soil in all most all the locations, its magnitude varies widely from location to location. The analysis reveals that the application of mixed fertilisers (organic manure based) adds more of the nutrient to soil as compared to the pure chemical fertilisers. The phosphorous enrichment in the soil is extremely essential to maintain a nutrient balance in the soil, as the farmers often neglect this important nutrient and substitute it by over use of nitrogenous fertilisers. It also reinforced that organic manure is more helpful in sustaining balanced soil health.

Potash Content

The combination treatments are, by and large, more potashenriching in the soil particularly after rice-wheat rotation. Perhaps, the artificial application of fertiliser treatment releases the nutrients rapidly in the field in most of the stations, with a exception of a few reverse cases. The crop seems to meet demand for potash from the soil rather than from the externally applied potasic fertiliser in these locations, which resulted to reduction of the stock of the soil nutrient.

The analysis of nutrient status after the cultivation of rice-wheat sequence with respect to initial values brings out important issues as under:

(1) The cultivation of continuous cereal crop rotations depletes soil nutrients such as organic carbon, native nitrogen, phosphorous and potash content in majority of the cases. The magnitude of the changes depends on the basic properties of soil. It has thus emphasised the need for region specific policy of induced fertilisation of soil through artificial chemicals to maintain the nutrient balance.

(2) The combination treatments of inorganic fertiliser and organic manure are more efficient in terms of upkeep of the nutrient balance in soil, quality and health of soil as compared to pure chemical fertiliser treatments.

(3) The relationship between degradation of soil quality in the experimental stations (where all factors of production are controlled) and the declining trends in yield of cereal crops is an important indicator of un-sustainability, particularly in case of pure chemical fertilisers.

Marginal Value Product of Fertiliser Treatments

The organic manure based treatments not only exhibit gain in yield but also have definite cost advantage.

The estimated marginal value addition to fertiliser treatments to various fertiliser treatments as presented in Chart 1. The profit per rupee investment on pure fertiliser (Rs.1.11 for NPK4) is lesser than that on combination treatments (Rs.1.38 for treatment NPK1FYM1 Rs.1.62 for treatment NPK1CR1 and Rs.1.91 for treatment NPK1GM1). Besides, the higher economic gains, the combination fertilisers also potentially mitigate the environmental externality of continuous cereal-cereal sequential cropping. The economic returns as well as the intangible ecological benefits (as explained earlier) clearly indicate that combination fertiliser is more income enhancing as well as ecologically beneficial in the long run.

The experimental trials have shown that the absolute yield response to chemical fertilisers either stagnates or declining at the experimental stations in the long run (chart 2).

Chart 3 depicts the trend pattern of crop yields in the experimental stations.

Indicators of Sustainable Production System

The indiscriminate use of chemical fertilisers gives rise to problems with long-run implication on environmental sustainability. The irreversible effects of the externality on the environmental resources such as hidden secondary salinity, ground water contamination, etc., are more serious than the economic ones. The scientific investigation has shown the traces of increasing level of nitrate in ground water in North India due to intensive fertiliser use in the farm fields (Singh, 1998, Kanwar *et al.*, 1998).[2] These are serious and complex problems require careful developed measures such as appropriate indicator of sustainability of technology options and monitoring mechanism. Three treatments are selected representing major groups of treatments to demonstrate the role of the indicator of sustainability. The experimental data on the selected treatments are used to develop three sets of sustainability indicators as discussed below:

Chart 1 *Marginal value product of fertiliser treatments*

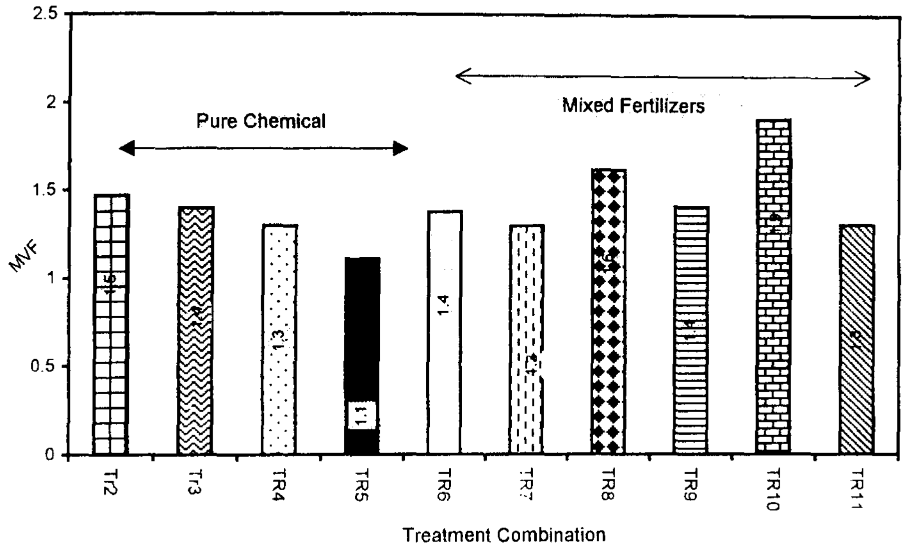


Chart 2 *Trend of average experimental yields of paddy for selected treatments*

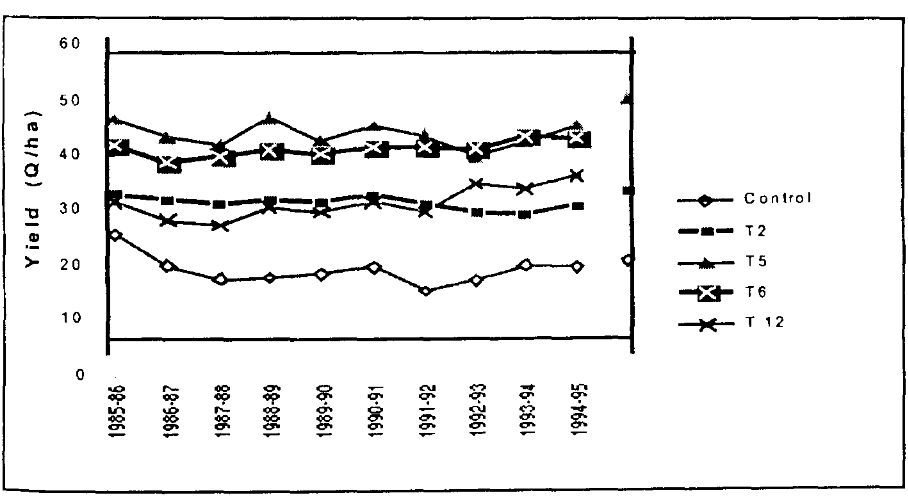


Chart 3 *Depicts the trend pattern of crop yields in the experimental stations*

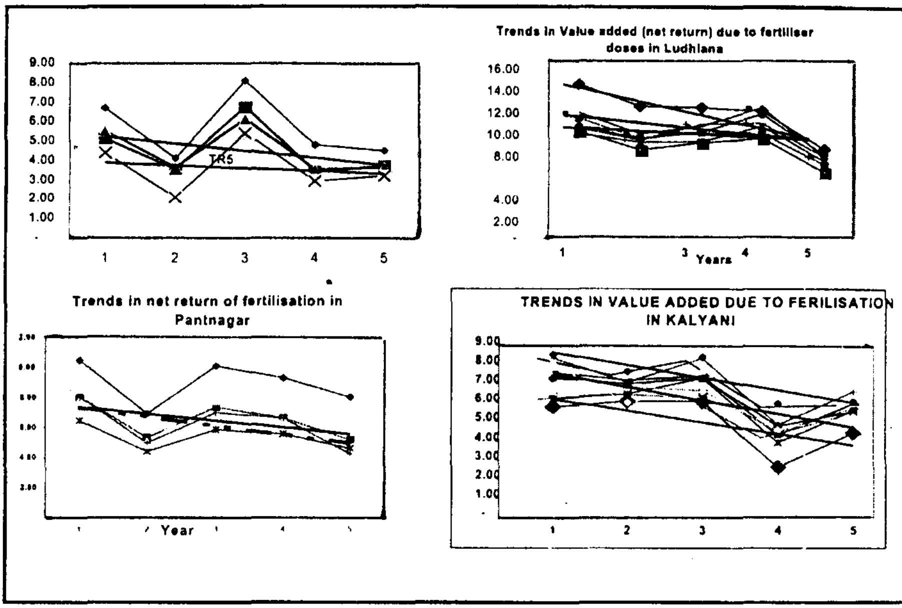
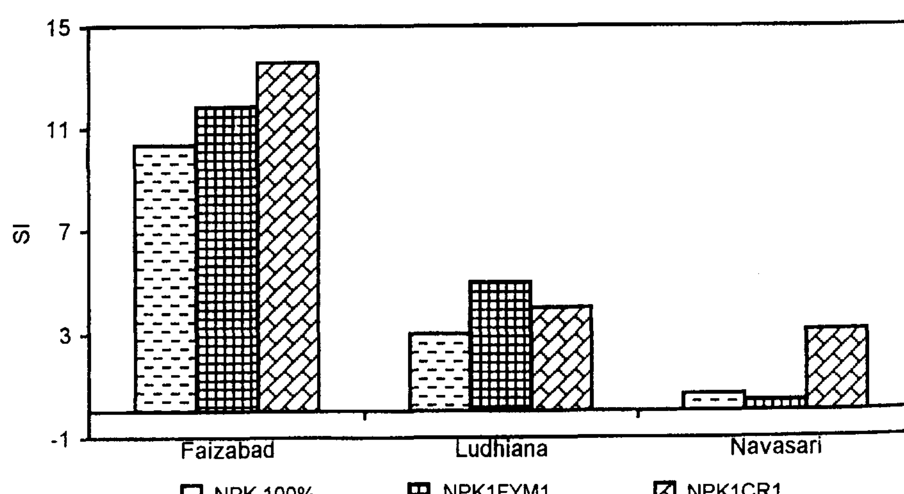


Chart 4 *Indicator of sustainability*



(a) Economic indicator combines biological factors, market factors and productivity growth.
Explanation: The first difference of the net return of the t and (t-1)th year (termed as FDR) is a measure of sustainability in the short run. A positive FDR shows an improved performance in the current year as compared to previous year and a negative denotes deterioration. Since the short-run weather risk influences the FDR, an average of FDR over the entire period along with its standard deviation indicates long-run sustainability. Ideally, a positive average value and lower standard deviation denote a state of sustainability and a negative the unsustainability of the production process.

(b) Physical indicator is derived from the status of soil health after continuous crop rotation.
Explanation: Changes in soil status (depletion/accumulation of soil nutrients such as organic carbon, nitrogen, phosphorous and potash contents) influence the land productivity. Some nutrients deplete rapidly upon continuous crop rotation and others get build up at the same time depending upon the soil condition.

(c) Biological indicator is derived from measurements of plant characteristics.
Explanation: A positive first difference of physical yields (FDY) shows whether the yield performances improve or deteriorate over time. But as the yield is a function of factors of production and the factors of production are sensitive to market prices, physical indicator of sustainability when confronts the market conditions fails to provide efficient measure of sustainability and distorts the decision criteria drastically. Under the circumstances, a unified measure of biological, physical and economic indicators is a more efficient measure.

Table 7 (also see Chart 4) combines the values of three sets of indicators of the sustainability of crop productivity and derive the unified indicator of sustainability. As the complete set of required data is not available for all the stations, the unified indicator of Faizabad, Ludhiana and Navasari is calculated. The measure indicates that the treatments NPK+FYM and NPK with crop residues are more sustainable than the pure chemical fertilisers. In general, the organo-chemical treatments as a group is more yield sustaining and cost effective than the pure chemical fertilisers. The soil-enriching property of the treatments and improved productivity property make the mixture treatments more efficient and eco-friendly. Thus, the balance mixture of organic and inorganic fertilisers must be promoted effectively in order to ensure sustainability. In this context, it is important to spread the message of comparative and sustainable benefits of technological options and convince the users to pursue dynamic cropping pattern with greener crop system as well as re-using the residues. Maximising long-run social as well as ecological benefits through sustainable cropping practice is preferred to short-term private gain.

NOTES

1. (See on declining trends in productivity of rice-wheat system; Chaudhury and Harrington (1993) in Haryana; Kumar and Joshi (1998) in Indo-Gangatic region; Hodds and Morris (1996) in Souh Asia; Paroda Woodhead and Singh (1994) in Asia; and Sinha (1998) in Punjab and Haryana.
2. The gaseous oxides of N derived from N fertilisation are highly reactive and pose threats to stability of ozone layer. The consumption of N-fertiliser in India was 9.5 million tonnes (FAI, 1995) with urea as dominant group. Urea when applied to soil transform into the NH^{+}_4 and NO_3 form, which are plant usable form. Water plays an important role NH^{+}_4 –N and NO_3- --N use and loss by affecting their mobility towards or away from plant roots. It also influences the evolution of gaseous N product N_2O, which lends to readily escape the soil and soil-plant system (Katyal and Reddy, 1997).

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