Residual Effects of *Sesbania sesban* Forestry on Yield and Nitrogen Uptake by Rice and Wheat in a Reclaimed Alkali Soil in Haryana

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Abstract

A 4-year-old plantation of a nitrogen (N)-fixing tree, *Sesbania sesban*, raised in a reclaimed alkali soil in northwest India was harvested. The biomass was removed and rice and wheat were grown for the next 6 years without application of fertilizer N. Yield and N uptake in crops, and changes in soil properties were compared with fallow control plots in which rice and wheat were grown without or with application of 120 kg urea-N ha^{-1}. Maximum residual benefit of *Sesbania* was observed in the first two years, after which yields of rice stabilized at 5.3 t ha^{-1} compared to 4.1 t ha^{-1} in control. Wheat yields stabilized at 1.9 t ha^{-1} in *Sesbania* plots in comparison to 1.5 t ha^{-1} in control. With application of 120 kg urea-N ha^{-1} average yield of rice was 6.4 t ha^{-1} and that of wheat was 4.6 t ha^{-1}. The residual effects of *Sesbania* resulted in additional grain production of 1.2 t ha^{-1} of rice (+26.4%) and 0.5 t ha^{-1} of wheat (+24.1%) each year. Apparent N uptake efficiency from applied urea-N was 33.4% in rice and 54.5% in wheat. Additional crop N uptake each year in *Sesbania* plots was 30.8 kg N ha^{-1} (20.6 kg in rice and 10.2 kg in wheat). The fertilizer-N equivalence of this residual effect amounted to 80.4 kg of urea-N ha^{-1}. Soil organic carbon, total N, available N, and microbial activity in *Sesbania* plots were at par with or were higher than 120 kg N ha^{-1} plots.

Introduction

Degraded soils such as salt-affected soils are low in organic matter and nitrogen (N), and have low biological activity (Rao and Ghai 1985). Growing N_2-fixing trees is beneficial not only for economic products but also for soil amelioration (Gill and Abrol 1987; Gill et. al. 1990; Singh et al. 1993). The beneficial effects of trees on yields of crops grown concurrently, in spatial-zoned (alley farming) or spatial-mixed (trees in crop land) agroforestry systems have been well described (Dommergues 1987) but systematic research on rotations of trees and crops over a period on the same piece of land (sequential agroforestry) is lacking. In the present investigation, field experiments were carried out in a reclaimed alkali soil in northwestern India on a sequential agroforestry system.

Materials and Methods

The experimental site was located on the Central Soil Salinity Research Institute (CSSRI) farm (field D5, Block 2), Karnal (29°N and 76°E), in northwest India, which falls in agroecoregion 4 (hot semi-arid ecoregion with alluvium derived soils) (Sehgal et al. 1992). The climate of the region is characterized by hot and dry summer and cool winter. The maximum temperature rises to about 46°C in summer and minimum temperature falls to 2°C in winter. The mean annual precipitation is 750 mm, a major portion of which is received during the

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southwest monsoon from July to September. Rainfall is about 50% of the mean annual potential evapotranspiration. The soil moisture regime is ustic while soil temperature regime is hyperthermic. The water table in the area fluctuated between 5 m and 7 m during the experiment.

The soil is representative of a reclaimed alkali soil, which occupies about one million ha of the Indo-Gangetic alluvial plains. It is classified as Typic Natrustalf, and is loamy in texture (48% sand, 32% silt, and 20% clay). Prior to experimentation the site was reclaimed by addition of gypsum (5 t ha^{-1}) in 1973. During 1974–78 rice (*Oryza sativa* L.) was grown in summer and wheat (*Triticum aestivum* L.), oats (*Avena sativa* L.), mustard (*Brassica* sp), clover (*Trifolium* sp), and lentil (*Lens culinaris* Medic.) in winter but yields were poor to average. In 1979–83, rice-wheat rotation was practiced with green manuring with *Sesbania cannabina* (Retz.) Poir. in summer for two years. The field was laid fallow during 1984. During ten years of cultivation (1973–83) on an average 75 kg N ha^{-1} as urea or calcium ammonium nitrate, 20 kg P_2O_5 ha^{-1} as single superphosphate, and 12 kg $ZnSO_4$ ha^{-1} was applied to each crop. The experiment was laid out in 6 m × 6 m plots. At the time of raising tree plantation in 1985, soil samples were removed with a screw-auger from 3 spots at random from 0–15 and 15–30 cm depth, and each sample was analyzed separately. The pH was measured in 1:2 soil-water suspension and ranged from 8.6 to 8.8 in 0–15 cm and from 9.2 to 9.5 in 15–30 cm soil depths. Organic carbon determined by wet digestion method (Walkley and Black 1934) ranged from 0.71% to 0.82% and 0.47% to 0.50% in the two soil layers. Total N was determined by steam distillation method (Bremner 1965), using a Kjeltec N analyzer (Tecator Inc., Sweden). Total N was 0.080–0.086% and 0.064–0.070% in the two soil layers. Available N was analyzed by hot alkaline permanganate method of Subbiah and Asija (1956), $NaHCO_3$ extractable phosphorus (P) by Olsen's method (Olsen et al. 1954), and 1N ammonium acetate extractable potassium (K) by flame photometry. Available N, P, and K were 74, 16, and 80 kg ha^{-1} respectively in surface soil. Soil properties were also determined after tree growth (Table 1).

Sesbania sesban (L.) Merr. seedlings were raised in polythene bags and transplanted in May 1985 in field plots at 1 m plant to plant distance and row spacing of 0.5, 1.0, 2.0, and 3.0 m to achieve densities of 20, 10, 5, and 3.3 × 10^3

Table 1. Salient properties of soil samples after tree growth and prior to planting of rice in rice-wheat system at Karnal, India[1].

Treatment	Soil layer (cm)	pH	EC (dS m^{-1})	OC (%)	Total N (%)	Available N (kg ha^{-1})
Tree[2] (*Sesbaria*)	0–15	8.5	0.38	0.85	0.086	138.1
	15–30	9.1	0.47	0.51	0.056	109.7
Fallow (N_0 plots)	0–15	8.2	0.36	0.81	0.083	154.0
	15–30	9.2	0.52	0.48	0.057	128.3
Fallow (N_{120} plots)	0–15	7.9	0.28	0.81	0.082	142.3
	15–30	8.7	0.29	0.53	0.059	128.3

1. EC=Electical conductivity; OC=Organic carbon; and N=nitrogen.

2. Sampled after removal of litter of *Sesbania* trees from the field.

plants ha^{-1} respectively. The four treatments were replicated four times in a randomized block design. The saplings were irrigated at establishment stage in the first year. In subsequent years, two irrigations were applied during summer before onset of monsoon rains after which no irrigation was applied. The underground irrigation water used in the experiments was non-saline. No fertilizers were applied during four years of *Sesbania* growth because the site had been continuously fertilized for the previous 11 years.

In 1989, the trees were harvested, biomass was removed, and the litter was left in the field. The woody biomass production in the four spacings ranged from 44.6 t ha^{-1} to 101.0 t ha^{-1} (oven-dry). The amount of N in the litter for the four spacings was 220–247 kg ha^{-1} (Rao et al. 1990). The plots were flooded with water to initiate decomposition of litter and root residues of trees, puddled manually, given a basal application of 40 kg P_2O_5 ha^{-1} as single superphosphate and 10 kg $ZnSO_4$ ha^{-1}. Nitrogen fertilizers were not applied. Seedlings of rice cv Jaya were transplanted in July in rows 20 cm apart with 15 cm between hills, placing 2 plants per hill. Adjacent plots (control) left fallow for 4 years served as control; rice was grown in these with P and zinc (Zn) application as above but urea was applied at 4 rates, 0, 40, 80, and 120 kg N ha^{-1} to quantify residual effect of biologically fixed N in tree plots in terms of urea-N equivalence. Nitrogen was applied by broadcasting, 50% of the dose at 2–3 days after transplanting (DAT) and 25% each at 21 and 42 DAT. Standing water (8–10cm) was maintained in rice throughout its growth. After harvest of rice, the field was plowed and wheat cv HD 2009 was sown in November in rows 20 cm apart. Phosphorus and Zn fertilization was same as for rice. Nitrogen was applied at 50% of recommended dose as basal dose prior to sowing, and 25% each was applied by broadcasting at 21 and 42 days after sowing along with irrigation. Grain and straw yields and their N content were measured at harvest. The straw was cut at 5 cm height and removed from the field. The field lay fallow for 2½ months in summer between harvest of wheat in mid-April and rice transplanting in late June. Grain yield of rice is expressed on 14% moisture basis and that of wheat on air-dry basis. Since variations in rice and wheat yields between the different planting densities of *S. sesban* were non-significant, only mean values are presented. Yields of rice and wheat were recorded for all 4 levels of applied N but that of only 0 and 120 kg N ha^{-1} is presented since yield response indicated continuous increase up to 120 kg N ha^{-1}. Moreover 120 kg N ha^{-1} is the recommended dose of N application for rice and wheat, so the residual effects are discussed only in relation to this rate of N application. Soil samples of three replicate plots of each treatment were pooled after each harvest and their organic carbon, total N, and available N content were analyzed. After residual effects of soil N build-up had leveled off and yield levels of rice and wheat had stabilized, more sensitive indicators of soil quality such as CO_2 evolution (Pramer and Schmidt 1964) and dehydrogenase activity (Casida et al. 1964) were measured in duplicate samples in the last two years to see if any effects of tree growth still remained.

Results

Rice and wheat yields

The grain yields of rice and wheat in *Sesbania*-N_0 (hereafter called *Sesbania* plots) and fallow-N_0 (hereafter called control plot) were high in the first 2 years and thereafter declined and remained steady for the next 4 years. In *Sesbania* plots yield of rough rice averaged 6.5 t ha^{-1} in first 2 years compared to 5.3 t ha^{-1} in control (Table 2); in the next 4 years it was 5.3 t ha^{-1}, compared to 4.1 t ha^{-1} in control. Averaged over 6 years , rice yield following *Sesbania* was 5.69 t ha^{-1} compared to 4.5 t ha^{-1} in control (Table 2) and 6.41 N_{120} t ha^{-1} in fallow-N_{120} plots (hereafter called N_{120} fertilized plots). On an average rice yield in *Sesbania* plots was 1.2 t ha^{-1} higher than in control plots throughout the six years, and the effect was statistically significant in five out of six years of cropping. The difference in rice yields of *Sesbania* and N_{120} fertilized plots was statistically not significant in all the six years. Wheat yields in *Sesbania* plots averaged 2.0 t ha^{-1} compared to 1.5 t ha^{-1} in control. The yield difference between the two treatments was statistically significant only in 2 out of 6 years. However, averaged over 6 years the residual effect of *Sesbania* was significant. An increased incidence of *Phalaris minor* Retz. and other weeds was noted in *Sesbania* and control plots due to thinner plant stand in these unfertilized plots (weedicides were not used). In contrast to rice, the N_{120} fertilized plots had significantly higher yields of 4.6 t ha^{-1} compared to *Sesbania* plots and weed infestation was not a problem because vigorous tillering, and good early growth supressed weed growth. Yields of rice and wheat straw did not differ between *Sesbania* plot and control plot but were significantly superior in N_{120} fertilized plots (Table 2). Thus on average 1.2 t ha^{-1} of rough rice and 0.5 t ha^{-1} of wheat grain could be additionally harvested in *Sesbania* plots compared to control.

Nitrogen content and uptake

The N content of rice and wheat grains and straw did not differ significantly between *Sesbania* plot and control plot (Table 3). Fertilization with 120 kg N ha^{-1} resulted in high N content in rice grain but not in wheat. Total N uptake by rice averaged 71.3 kg ha^{-1} yr^{-1} in *Sesbania* plots which was significantly higher than that obtained in the control (50.7 kg ha^{-1}). The N uptake in N_{120} fertilized plots was 90.8 kg ha^{-1} and superior to

Table 2. Grain and straw yields of rice and wheat grown in plots after harvest of 4-yr-old *Sesbania sesban* trees and on adjacent fallow plots at Karnal, India.

Treatment	N applied (kg ha^{-1})	Grain (t ha^{-1})			Straw (t ha^{-1})		
		1989–90	1991–94	Mean[1]	1989–90	1991–94	Mean[1]
Rice[2]							
Tree	0	6.5	5.3	5.69	5.2	2.9	3.70
Fallow	0	5.3	4.1	4.50	3.5	2.2	2.63
Fallow	120	6.7	6.3	6.41	6.3	3.8	4.63
LSD (P=0.05)		–	–	0.83	–	–	1.41
Wheat							
Tree	0	2.2	1.9	1.99	2.5	2.7	2.63
Fallow	0	1.6	1.5	1.51	2.4	2.2	2.23
Fallow	120	4.8	4.5	4.58	5.6	6.0	5.90
LSD (P=0.05)		–	–	0.37	–	–	0.75

1. Average of 6 years.

2. Rice grain yields expressed on 14% moisture basis.

Table 3. **Nitrogen (N) content in grain and straw of rice and wheat grown in plots after harvest of 4-yr-old *Sesbania sesban* trees and on adjacent fallow plots at Karnal, India.**

Treatment	N applied (kg ha^{-1})	Grain N (%) 1989–90	Grain N (%) 1991–94	Grain N (%) Mean[1]	Straw N (%) 1989–90	Straw N (%) 1991–94	Straw N (%) Mean[1]
Rice							
Tree	0	1.1	1.0	1.03	0.6	0.5	0.54
Fallow	0	0.9	1.0	0.98	0.5	0.5	0.47
Fallow	120	1.2	1.1	1.14	0.7	0.6	0.59
LSD (P=0.05)		–	–	0.10	–	–	0.07
Wheat							
Tree	0	1.4	1.3	1.35	0.3	0.4	0.37
Fallow	0	1.2	1.3	1.25	0.3	0.4	0.35
Fallow	120	1.5	1.5	1.51	0.4	0.4	0.39
LSD (P=0.05)		–	–	NS[2]	–	–	NS

1. Average of 6 years.

2. NS=not significant.

Sesbania plots (Table 4). In wheat, N uptake in *Sesbania* plot was 36.7 kg ha^{-1} and was significantly better than in control (26.5 kg ha^{-1}). It was highest in N_{120} fertilized plots (91.9 kg ha^{-1}). Thus an additional amount of N averaging 20.6 kg ha^{-1} in rice and 10.2 kg ha^{-1} in wheat was taken up by the crops each year over and above the control plots.

Table 4. **Total nitrogen (N) uptake by rice and wheat grown in plots after harvest of 4-yr-old *Sesbania sesban* trees and on adjacent fallow plots at Karnal, India.**

Treatment	N applied (kg ha^{-1})	N uptake (kg ha^{-1}) 1989–90	N uptake (kg ha^{-1}) 1991–94	N uptake (kg ha^{-1}) Mean[1]
Rice				
Tree	0	91.4	61.2	71.3
Fallow	0	60.8	45.6	50.7
Fallow	120	107.4	82.5	90.8
LSD (P=0.05)		–	–	17.8
Wheat				
Tree	0	37.0	36.5	36.7
Fallow	0	24.8	27.4	26.5
Fallow	120	93.0	91.4	91.9
LSD (P=0.05)	–	–	–	10.0

1. Average of 6 years.

Soil properties

Even after growing 12 crops, 6 each of rice and wheat and harvesting an additional amount of 30.8 kg N ha^{-1} each year in the crops, there was no significant decline in total or available N in the soils of the *Sesbania* plots compared to N_{120} fertilized plots (Table 5). Barring an exception, the soil biological activity in *Sesbania* plots was comparable to the N_{120} fertilized plots or even higher in some years (Table 6) showing no deterioration in soil biological properties as a result of cropping without N fertilization.

Discussion

The maximum residual effect of previous tree growth on rice was observed in first two years because of rapid decomposition of the leaf litter under favorable moisture and temperature regimes during rice cultivation. Rapid decomposition of *Sesbania* shoots (Ghai et al. 1988; Rao and Pathak 1996) and roots (Palm et al. 1988) has been reported earlier. This resulted in yields of 6.5 t ha^{-1} which were at par with 120 kg urea-N (6.7 t ha^{-1}) (Table 2). By the time wheat is grown in winter the initial build-up of organic matter is depleted by microbial oxidation and cropping. The low temperatures during winter result in lower microbial activity and N release from organic matter. So the effects on wheat yields are marginal.

Table 5. Salient properties of soils at the end of six years of rice and wheat cropping in rice-wheat system at Karnal, India during 1994.[1]

Treatment	Soil layer (cm)	pH	EC (dS m^{-1})	OC (%)	Total N (%)	Available N (kg ha^{-1})
Tree (*Sesbania*)	0–15	7.5	0.25	0.76	0.083	77.2
	15–30	8.3	0.34	0.36	0.056	57.2
Fallow (N_0)	0–15	7.1	0.24	0.62	0.084	63.0
	15–30	7.2	0.19	0.48	0.067	56.0
Fallow (N_{120})	0–15	7.0	0.15	0.66	0.077	77.0
	15–30	7.3	0.15	0.30	0.060	63.0

1. EC=Electrical conductivity; OC=organic carbon; and N=nitrogen.

Table 6. Soil biological properties after harvest of rice (R) and wheat (W) during 4th to 6th year of cropping under different treatments at Karnal, India.[1]

Treatment	CO_2 evolution (mg 100g^{-1} soil)					Dehydrogenase (gTPF g^{-1} d^{-1})
	W4	R5	W5	R6	W6	W6
Tree (*Sesbania*)	71.0a	42.3a	38.7a	45.9a	98.9a	74.5a
Fallow (N_0)	35.4b	46.4a	43.2b	34.8b	74.2b	76.6a
Fallow (N_{120})	89.8c	24.3b	35.5a	66.3c	102.6a	66.9b

1. Values followed by the same alphabet in each column are not significantly different from each other (P=0.05).

The residual effect of *Sesbania* reduced from third year onwards but sustained yields of rice and 5.3 t ha^{-1} yr^{-1} of rice grain were obtained in the later years which were higher than the control yields of 4.1 t ha^{-1}. Residual effect of *Sesbania* in wheat was only statistically significant and yields stabilized at 1.9 t ha^{-1} from 3rd year which were low as compared to that obtained with N_{120} fertilization but higher than control yields of 1.5 t ha^{-1}.

In control plots too yields were higher in first 2 years (5.3 t ha^{-1}) compared to later 4 years (4.1 t ha^{-1}). The N uptake in crops in first two years was 60.8 kg compared to 45.6 kg in the next 4 years; the difference of nearly 15 kg N ha^{-1} represents N gains during 4 years of fallow prior to rice-wheat cropping.

Rice is ideally suited for utilization of organic sources of N because of favorable temperature and moisture conditions during its growth, which promotes mineralization of N from organic matter. It can assimilate ammonia directly as it is slowly released by decomposition of organic matter. The tight coupling of release and plant uptake, results in lesser gaseous losses and greater N uptake efficiency. Rice is, however, a poor user of urea-N; rarely more than a third of the applied N is recovered due to significant gaseous losses. In the present study, averaged over 6 years rice recovered only 33.4% of applied urea-N whereas wheat recovered 54.5% due to better response to urea-N fertilization. Total N uptake in 6 crops of rice was 427.5 kg ha^{-1} in *Sesbania* plots compared to 303.9 kg ha^{-1} in control plots (fallow). The difference of 123.6 kg amounts to an additional N supply of 20.6 kg ha^{-1} yr^{-1} in *Sesbania* plots. Based on fertilizer-use efficiency, an application of 61.7 kg urea-N ha^{-1} would be required to produce this increase.

Similarly in wheat, total N uptake was 220.1 kg ha^{-1} in *Sesbania* plots compared to 159.0 kg ha^{-1} in the control. The difference of 61.1 kg amounts to an additional supply of 10.2 kg ha^{-1} yr^{-1} or an urea-N equivalent of 18.7 kg ha^{-1}. Thus a sustained benefit of 30.8 kg N ha^{-1} (20.6 kg in rice and 10.2 kg in wheat) which is equivalent to 80.4 kg of urea-N ha^{-1} yr^{-1} application and could be obtained with a one-time planting of N_2-fixing trees for 4 years.

Comparable studies on tree effects in sustaining crop yields have not been reported. So the present results are compared with annual green manuring with *Sesbania* spp. There have been many reports on rice but few on wheat. Palm et al. (1988) reported rapid mineralization of leaf and root material of *Sesbania sesban* (grown as an annual for 84 days and green manured) and beneficial effects on rice. The N benefits from green manuring in rice have been reported to range from 60 to 100 kg N ha^{-1} (Ghai et al. 1988; Kolar et al. 1993; Singh et al. 1994). Swarup (1992) reported beneficial influence of *Sesbania* green manuring on electrochemical properties and nutrient availability in sodic soils and obtained additional grain yield of 1.48 t ha^{-1} of rice and 0.66 t ha^{-1} of wheat. Kolar et al. (1993) also reported that green manure increased wheat yields by 0.4 t ha^{-1}. Singh et al. (1994) reported residual effect of *Sesbania* applied to rice on subsequent wheat, but only after 2 years of application.

In *Sesbania* plots even after initial benefits of residual effect of *S. sesban* growth in the first two years, a steady supply of 31 kg N ha^{-1} yr^{-1} was observed. What is the source of this additional N? For centuries Asian farmers have been harvesting low but significant rice yields of about 1 t ha^{-1} without any N application; such productivity has been ascribed to non-symbiotic N_2-fixation (Singh 1961). Even after growing 12 crops without addition of N in *Sesbania* plots, soil organic carbon, total and available N, and microbial activity were maintained on par or were high as compared to plots in which 120 kg N ha^{-1} was applied (Tables 5 and 6). The steady supply of N required to sustain productivity in the later part of the study may therefore be of biological origin, i.e., through non-symbiotic N_2-fixation. Although non-symbiotic N_2-fixation would take place in control plots too, but higher organic matter inputs in tree plots would create better physico-chemical environment for microbial activity. It is significant that even in a reclaimed alkali soil subject to cropping for 11 years, soil properties could be improved by tree plantation to an extent that productivity benefits and N gains could be obtained on a sustained basis for 6 years after the harvest of trees. The residual effect of *Sesbania* on rice yield was much greater than on wheat. This may be due to greater net N mineralization in flooded soils (De Datta 1981). The observed beneficial effect of tree planting need not be ascribed only to N effect. A portion of it would also be due to non-N rotational effects caused due to improved physical properties, higher biological activity, mycorrhizal activity, and greater availability of micronutrients, which were not measured in the present study but have been reported by others. For example, volumetric water content of soils after rice harvest was higher in *Sesbania* plots and effects were evident after wheat crop also (Joshi et al. 1994); also they had greater structural stability and higher hydraulic conductivity than NPK plots after *Sesbania* green manuring. Somani and Saxena (1991) showed that of all the organic materials, *Sesbania* resulted in highest improvement in soil microflora and wheat growth in a calcareous soil. Rao and Pathak (1996) showed that addition of *Sesbania* results in dramatic increase in dehydrogenase (biological) activity and microbial biomass of alkali soils.

It is concluded that raising N_2-fixing tree plantations even in reclaimed alkali soils is beneficial for improving soil quality and sustainability. The results of 6 years of rice and wheat cultivation without application of fertilizer N after harvesting a plantation of *Sesbania sesban*, showed that rice yields could be sustained at moderate levels of 5.3 t ha^{-1} almost comparable to 120 kg N ha^{-1} applied on fallow plots but wheat yields were low (1.9 t ha^{-1}). Additional yields of 1.2 t ha^{-1} of rice and 0.5 t ha^{-1} of wheat were obtained every year over fallow-control plots. Rice is ideally suited to utilization of organic sources of N or N_2- fixation because of warmer temperatures and favorable moisture regimes during its growth. Additional N availability of 20 kg ha^{-1} yr^{-1} in rice and 10 kg ha^{-1} yr^{-1} in wheat may be due to non-symbiotic fixation. For optimizing resource mix for achieving sustained productivity, it is desirable to rely on organic sources for rice, reduce rates of fertilizer N for rice and use it instead for wheat. If this experiment were to be redesigned, the following changes will provide valuable information and give a sharper focus to conclusions already drawn:

- Control plots (minus trees) would be subject to rice-wheat cropping instead of being left fallow in the initial 4 years, which would bring out the real differences between the two. The present results of N gains of 30 kg ha^{-1} yr^{-1} in *Sesbania* plots is a slight underestimate because of N gains during fallow in control plots.
- In *Sesbania* plots, 50% of the recommended N dose, i.e., 60 kg N ha^{-1} and in wheat 75% of recommended dose, i.e., 90 kg N ha^{-1} would be applied to have a proper blend of organic and inorganic resources and achieve sustained and higher productivity compared to application of urea at 120 kg N ha^{-1}.

- Changes in soil physical properties and in P, K, and micronutrients would be measured.

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