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Evaluation of sustainable nutrient management practices based on land degradation and rainfall effects on soybean yield and organic carbon and available N content in rainfed vertisols

ABSTRACT. Long term experiments with nine organic and inorganic fertilizer treatments. Control, 20 kg N+13 kg P, 30 kg N+20 kg P, 40 kg N+26 kg P, 60 kg N+35 kg P, FYM 6 t/ha+20 kg N+13 kg P, soybean residue 5 t/ha+20 kg N+13 kg P, FYM 6 t/ha and soybean residue 5 t/ha were conducted in semi-arid vertisols at Indore, Madhya Pradesh, India, during 10 *kharif* seasons from 1992 to 2001 with the objective of identifying the most sustainable nutrient management practice for soybean (cv. JS–335) in the region. For this purpose, procedures of regression and sustainability index were used for evaluating the impact of integrated fertility management practices on soil health and crop productivity. There was a significant land degradation effect on the yield over the years as indicated by the negative slope of years in the regression model. The predictability of yield through land degradation variable ranged from 0.176 for control to 0.381 for 60 kg N+35 kg P per hectare treatment. Predictability of the yield through land degradation and rainfall was found to range between 0.277 for FYM 6 t/ha+20kg N+13 kg P to 0.507 for FYM 6 t/ha treatment. Using the treatment means, estimates of error and yield potential of the crop, i.e. the maximum yield of 3051 kg/ha obtained in *kharif* 1993. The study indicated that application of FYM 6 t /ha+20 kg N+13 kg P per hectare is highly sustainable followed by 60 kg N+35 kg P per hectare for attaining maximum yield of soybean and significant build up of organic carbon and available N and P status in the soil. The paper also presents the experimental evidence of the impact of joint use of *in-situ* and *ex-situ* residue application, vegetative barriers coupled with cost effective land treatments on checking the erosion of carbon and available nutrients from agricultural lands.

KEY WORDS: sustainable practices; land degradation; rainfall effect; nutrient management

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Among all the uncontrollable factors of production, rainfall is the most important factor, since any change in its quantity and distribution would adversely affect the soil moisture status and reduce the crop yields to a significant extent [Sharma et al. 1999; Sharma, Gupta 2002]. There is a need to accurately measure the sustainability of rainfed practices for a given crop over a period of time by taking into account the effects of rainfall on the yield obtained in a given soil and the agro-climatic situation [Vittal et al. 2002]. If the same crop is grown in a piece of land every year, there is a possibility of land degradation and obtaining declining yields over a period of time. From long-term manurial experiments conducted in the same experimental site over the seasons, it is desirable to quantify the land degradation effect in terms of yield for assessing the actual effects and superiority of applied inputs. In dry-land agriculture, the fertilizer responses of a crop would vary in different seasons depending on the available soil moisture, which is directly influenced by rainfall, apart from available soil N, P and K and different micronutrients, and various other factors. Further, there is a need to judiciously adjust the applied nutrients for any crop with combinations of both organic and inorganic fertilizers in a given soil and agro-climatic situation. This is necessary to take care of the soil health and prevent it from degradation over the years. In addition, even under erratic rainfall situations, with suitable soil and water conservation measures, fertilizer practices which are sustainable for attaining consistently higher yields of a crop could be identified [Ranade et al. 2002]. Using the regression procedures discussed by Draper and Smith [1973] and Maruthi Sankar [1986], the estimates of the experimental error could be derived by calibrating regression models of yield with rainfall and land degradation variables. Based on the procedure developed in the all India Coordinated Research Project for Dryland Agriculture [Vittal et al. 2002] for measurement of sustainability of rainfed practices, the estimates of the experimental error are further used to derive the sustainability of nutrient management practices over a period of time.

METHODS

Long-term manurial trials on soybean cultivar 'JS–335' genotype were conducted in the same site in a semi-arid vertisol of Indore from *kharif* 1992 to 2001 with a set of 9 organic and inorganic fertiliser treatments. The experiments were conducted with the objective of quantifying the effects of different sources and levels of N and P nutrients on soybean yield, apart from identifying the most sustainable fertiliser practice for the crop in semi-arid vertisols [Sharma 1996, 1997, 1998, 1999, 2000, 2001, 2002]. The organic and inorganic fertilizer treatments used in the experiments are: T1 – Control, T2 – 20 kg N + 13 kg P/ha, T3 – 30 kg N + 20 kg P/ha, T4 – 40 kg N + 26 kg P/ha, T5 – 60 kg N + 35 kg P/ha, T6 – FYM 6 t/ha + 20 kg N + 13 kg P/ha, T7 – Soybean residue 5 t/ha + 20 kg N + 13 kg P/ha, T8 – FYM 6 t/ha, T9 – Soybean residue 5 t/ha.

The experiments were conducted with three replications in a Randomized Block Design with a net plot size of 4.5 m x 6.4 m. The crop was grown with 30 cm row spacing with a seed rate of 100 kg/ha. Urea, diammonium phosphate (DAP) and farmyard manure (FYM) were the sources of nutrient. FYM was applied 10 days prior to the sowing of soybean. The soybean crop residue treatment was applied as surface mulch after emergence of the crop in each of the 10 seasons. The initial soil test values were found to range from 166 to 216 kg/ha for N, 42 to 60 kg/ha for P, 640 to 1215 kg/ha for K and 5.24 to 11.38 kg/ha for sulphur in the long-term study. The rainfall and its distribution were not uniform during the period of study. The annual rainfall ranged from 454 mm in the year 2000 to 1331 mm in the year 1996, with a mean of 876 mm and standard deviation of 272 mm. It had a variation of 31.1 % in 10 seasons. The rainfall and its distribution would influence the yield to a large extent under dry-land conditions, and hence any selection of sustainable fertiliser practices should be made only after taking into account the effects of rainfall on yield over a period of time.

The mean soybean yield of 1702 kg/ha with a standard deviation of 528 kg/ha and coefficient of variation of 32 % was observed over treatments in different seasons in the study. The fertilizer treatments provided a mean yield with a range of 1251 kg/ha in control (T1) with a variation of 39.8 % to 2022 kg/ha with an application of FYM 6 t/ha + 20 kg N + 13 kg P/ha (T6) with a coefficient of variation of 24.1 % in 10 seasons. The maximum potential yield of 3051 kg/ha in the study was also attained with the treatment T6 in *kharif* 1993, while the lowest yield of 691 kg/ha was attained in the unfertilized plot in *kharif* 1996. The coefficient of variation in soybean yields ranged from 24.1 (T6) to 39.8 % (T1) in the study period.

The analysis of variance of soybean yields indicated that the fertiliser treatments are significantly different from each other in all seasons. The yields attained with 9 fertiliser treatments in different years along descriptive statistics, viz., mean, standard deviation, coefficient of variation and critical difference between two treatments for comparison are given in Table 1. Out of 10 years, the highest yield was attained with the treatment T6 (FYM 6 t/ha + 20 kg N + 13 kg P/ha) in 7 seasons (1993, 1996 to 2001), T5 (60 kg N + 35 kg P/ha) in 2 seasons (1992 and 1994) and T3 (30 kg N + 20 kg P/ha) in one season (1995). Based on a graphical plot given in Figure 1, the soybean yields were found to be decreasing over the years, possibly due to a land degradation effect. The yields of each treatment have to be regressed with time in order to assess the effect of land degradation on the yield and its variation over a period of time as:

$$Y = \alpha + \beta\,(\text{Year}) \qquad (1)$$

where α is the intercept and β is the slope.

Similarly, the influence of rainfall (RF) on soybean yield could be assessed with a graphical plot of rainfall and yield as given in Figure 2. An increase in soybean yields was observed in all treatments up to about 800 mm of rainfall and a decreasing trend beyond. Hence, the yields have to be regressed with linear and quadratic variables of rainfall received in different years for assessing the influence of rainfall on yield as;

$$Y = \alpha + \beta_1\,(\text{RF}) + \beta_2\,(\text{RF})^2 \qquad (2)$$

where α is the intercept ; β_1 and β_2 are the slopes of linear and quadratic variables of rainfall. A multiple regression of yield with land degradation (LD) and rainfall variables could also be calibrated to assess the influence of both variables on yield over years as:

$$Y = \alpha + \beta_1\,(\text{LD}) + \beta_2\,(\text{RF}) + \beta_3\,(\text{RF})^2 \qquad (3)$$

where α is the intercept ; β_1 is the slope of land degradation ; β_2 and β_3 are the slopes of linear and quadratic variables of rainfall.

Based on the procedure developed by Vittal *et al*., (2002), the estimates of sustainability of nutrient management practices could be derived as:

$$\eta\,t = \frac{X - \delta}{Y_{max}}$$

where η_t is the estimate of sustainability of treatment 't'; X is the mean of treatment 't'; σ is the estimate of error based on a regression model yield attained with atreatment 't'; and Y_{max} is the highest yield attained in the study. Attempts were also made to consolidate the experimental evidence related to the impact of conjunctive use of *in-situ* and *ex-situ* residue application, vegetative barriers and land treatments on changes in organic carbon content in soils, erosion of nutrients and soil, productivity and water use efficiency of different rainfed crops grown on black clay soils at Indore, Madhya Pradesh, India.

RESULTS

Long term experiments with nine organic and inorganic fertilizer treatments viz., Control, 20 kg N + 13 kg P, 30 kg N + 20 kg P, 40 kg N + 26 kg P, 60 kg N + 35 kg P, FYM 6 t/ha + 20 kg N + 13 kg P, soybean residue 5 t/ha + 20 kg N +

Tab. 1

13 kg P, FYM 6 t/ha and soybean residue 5 t/ha were conducted in semi-arid vertisols at Indore during 10 *kharif* seasons from 1992 to 2001 with the objective of identifying the most sustainable nutrient management practice for soybean in Malwa region. The annual rainfall ranged between 454 mm in the year 2000 and 1331 mm in the year 1996, with mean rainfall of 876 mm and standard deviation of 272 mm. The mean yield of soybean ranged between 1251 kg/ha with a standard deviation of 498 kg/ha (Control) and 2022 kg/ha with a standard deviation of 487 kg/ha (FYM 6 t/ha + 20 kg N + 13 kg P). FYM 6 t/ha + 20 kg N + 13 kg P had lowest coefficient of variation of 24.1 %, while control had the highest coefficient of variation of 39.8 %.

Table 2. Regression diagnostics of soybean yield with land degradation over years at Indore

Treatment	Correlation	Regression equation	R^2	σ
Control	-0.420	Y = 139070 – 69.0 LD (105380) (52.8)	0.176	479
20 kg N + 13 kg P/ha	-0.484	Y = 160663 – 79.7 LD (101559) (50.9)	0.235	462
30 kg N + 20 kg P/ha	-0.554	Y = 200517 – 99.6 LD (105623) (52.9)	0.307	480
40 kg N + 26 kg P/ha	-0.602 *	Y = 204912 – 101.7 * LD (95344) (47.8)	0.362 *	434
60 kg N + 35 kg P/ha	-0.612 *	Y = 208638 – 103.5 * LD (94496) (47.3)	0.381 *	430
FYM 6 t/ha + 20 kg N + 13 kg P/ha	-0.462	Y = 150574 – 74.4 LD (100744) (50.5)	0.214	458
Residue 5 t/ha + 20 kg N + 13 kg P/ha	-0.451	Y = 167513 – 83.1 LD (115981) (58.1)	0.203	528
FYM 6 t/ha	-0.601 *	Y = 216570 – 107.6 * LD (101068) (50.6)	0.371 *	460
Residue 5 t/ha	-0.456	Y = 173268 – 86.1 LD (118378) (59.3)	0.208	539

Values in parentheses are standard errors of regression coefficients,
* Indicates significance at 5 % level
LD Land degradation, Y Yield (kg/ha), R^2 Coefficient of determination, σ Estimate of prediction error (kg/ha)

A declining trend in soybean yields was observed up to 1997 and an increasing trend later. Similarly, the yields were found to be consistently higher up to about 800 mm of rainfall and a declining trend beyond. Correlation and regression procedures were explored to determine an appropriate estimate of the experimental error and further use for determining the most sustainable practice. The rainfall and soybean yield were positively related with each other in all the nine treatments. Predictability of the yield through rainfall ranged between 0.005 for 40 kg N + 26 kg P per hectare and 0.138 for control treatment. There was a significant land degradation effect on the yield over the years as indicated by the negative slope of years in the regression model. Predictability of the yield through land degradation variable ranged between 0.176 for control and 0.381 for 60 kg N + 35 kg P per hectare treatment. Predictability of the yield through land degradation and rainfall was found to range between 0.277 for FYM 6 t/ha + 20kg N + 13 kg P and 0.507 for FYM 6 t/ha treatment. Using the treatment means, estimates of error and yield potential of the crop, i.e. the maximum yield of 3051 kg/ha attained in *kharif* 1993, the estimates of sustainability were derived based on the procedure developed by Vittal et al. [2002]. The study indicated that application of FYM 6t/ha + 20 kg N + 13 kg P per hectare is highly sustainable followed by 60 kg N + 35 kg P per hectare for attaining the maximum yield of soybean in the semi-arid vertisols of Indore in Madhya Pradesh.

Table 3. Regression diagnostics of soybean yield with rainfall at Indore

Treatment	Correlation	Regression equation	R^2	σ
Control	-0.219	$Y = 332 + 2.798\ RF – 0.002\ RF^2$ (1596) (3.795) (0.002)	0.138	524
20 kg N + 13 kg P/ha	-0.037	$Y = 442 + 2.899\ RF – 0.002\ RF^2$ (1649) (3.922) (0.002)	0.079	542
30 kg N + 20 kg P/ha	-0.037	$Y = 743 + 2.597\ RF – 0.001\ RF^2$ (1827) (4.344) (0.002)	0.054	600
40 kg N + 26 kg P/ha	-0.021	$Y = 1531 + 0.729\ RF – 0.0004\ RF^2$ (1763) (4.191) (0.002)	0.005	579
60 kg N + 35 kg P/ha	-0.002	$Y = 1506 + 1.084\ RF – 0.0006\ RF^2$ (1760) (4.185) (0.002)	0.010	578
FYM 6 t/ha + 20 kg N + 13 kg P/ha	0.106	$Y = 1134 + 2.007\ RF – 0.001\ RF^2$ (1647) (3.915) (0.002)	0.042	541
Residue 5 t/ha + 20 kg N + 13 kg P/ha	-0.091	$Y = 585 + 2.962\ RF – 0.002\ RF^2$ (1848) (4.393) (0.002)	0.078	607
FYM 6 t/ha	0.078	$Y = 376 + 3.359\ RF – 0.002\ RF^2$ (1793) (4.263) (0.002)	0.082	589
Residue 5 t/ha	-0.145	$Y = 242 + 3.679\ RF – 0.002\ RF^2$ (1840) (4.375) (0.002)	0.127	604

Values in parentheses are standard errors of regression coefficients
R^2 Coefficient of determination, σ Estimate of prediction error (kg/ha), RF Rainfall (mm), Y Yield (kg/ha)

Table 4. Regression diagnostics of soybean yield with land degradation and rainfall at Indore

Treatment	Regression equation	R^2	σ
Control	Y = 182077 (105554) – 91.125 (52.919) LD + 3.528 (3.379) RF – 0.002 (0.002) RF^2	0.423	463
20 kg N + 13 kg P/ha	Y = 190156 (108577) – 95.120 (54.435) LD + 3.661 (3.476) RF – 0.002 (0.002) RF^2	0.390	477
30 kg N + 20 kg P/ha	Y = 231802 (113661) – 115.85 (56.983) LD + 3.524 (3.639) RF – 0.002 (0.002) RF^2	0.439	499
40 kg N + 26 kg P/ha	Y = 225696 (109223) – 112.394 (54.758) LD + 1.628 (3.497) RF – 0.001 (0.002) RF^2	0.416	479
60 kg N + 35 kg P/ha	Y = 229817 (107507) – 114.473 (53.898) LD + 2.0002 (3.442) RF – 0.001 (0.002) RF^2	0.435	472
FYM 6 t/ha + 20 kg N + 13 kg P/ha	Y = 162697 (115646) – 81.006 (57.978) LD + 2.656 (3.703) RF – 0.001 (0.002) RF^2	0.277	508
Residue 5 t/ha + 20 kg N + 13 kg P/ha	Y = 203386 (124332) – 101.682 (62.333) LD + 3.776 (3.981) RF – 0.002 (0.002) RF^2	0.361	546
FYM 6 t/ha	Y = 242019 (106222) – 121.157 (53.254) LD + 4.328 (3.401) RF – 0.002 (0.002) RF^2	0.507	466
Residue 5 t/ha	Y = 218599 (119095) – 109.482 (59.707) LD + 4.556 (3.813) RF – 0.003 (0.002) RF^2	0.441	523

Values in parentheses are standard errors of regression coefficients, R^2 Coefficient of determination, LD Land degradation , Y Yield (kg/ha), σ Estimate of prediction error (kg/ha), RF Rainfall (mm)

Estimates of correlation of yield, land degradation and rainfall variables. Using the 10 year soybean yield data of different treatments, estimates of correlation were determined between the yield and the time period. The correlations were negative for all treatments indicating the possibility of land degradation over a period of time. The estimates of correlation between yield and land degradation ranged from – 0.42 in control plot (T1) to – 0.612 in the permanent plot, where 60 kg N + 35 kg P/ha (T5) was applied and they are given in Table 2.

The soybean yields were related to the amount of rainfall in 10 years. The treatment wise estimates of correlation between yield and rainfall ranged from – 0.219 in the control plot to 0.106 in the plot where FYM 6 t/ha + 20 kg N + 13 kg P/ha was applied (T6). The correlation estimates between yield and rainfall indicated that the yields increased with rainfall in all the treatments up to the rainfall of about 800 mm and decreased further. This is also due to the fact that the soybean crop would require about 500 mm of water for its average growth and yield. The estimates of correlation between soybean yield and rainfall are given in Table 3.

Table 5. Sustainability of integrated nutrient management practices for soybean using regression models of land degradation and rainfall at Indore

Treatment	Sustainability based on regression of yield with		
	Land degradation	Rainfall	Land degradation and rainfall
Control	0.269	0.253	0.271
20 kg N + 13 kg P/ha	0.371	0.355	0.372
30 kg N + 20 kg P/ha	0.429	0.413	0.430
40 kg N + 26 kg P/ha	0.449	0.434	0.451
60 kg N + 35 kg P/ha	0.493	0.477	0.495
FYM 6 t/ha + 20 kg N + 13 kg P/ha	0.522	0.506	0.524
Residue 5 t/ha + 20 kg N + 13 kg P/ha	0.407	0.391	0.408
FYM 6 t/ha	0.443	0.428	0.445
Residue 5 t/ha	0.369	0.354	0.371

Table 6. Changes in soil organic carbon content and available nutrients status of surface 0-15 cm soil layer after 9 years as influenced by joint use of organics and fertilizer nutrients

No.	Treatment	OC (%)	Available nutrients (kg/ha)			
			N	P	K	S
In the year 1992 i.e. Prior to experiment						
		0.51	204.00	7.12	385.0	22.78
After 9 years of experimentation, i.e. in 2000 (after harvest of soybean)						
1	Control	0.39	181.8	5.10	546	12.10
2	20 kg N + 13 kg P/ha	0.41	184.5	7.38	533	12.80
3	30 kg N + 20 kg P/ha	0.50	208.2	7.50	520	13.40
4	40 kg N + 26 kg P/ha	0.53	213.1	10.18	507	14.50
5	60 kg N + 35 kg P/ha	0.55	220.0	14.12	494	15.40
6	FYM 6 t/ha + 20 kg N + 13 kg P/ha	1.06	336.4	28.06	754	16.30
7	Residue 5 t/ha + 20 kg N + 13 kg P/ha	0.95	325.3	10.23	663	14.90
8	FYM 6 t/ha	1.02	332.6	13.52	727	15.00
9	Residue 5 t/ha	0.60	231.0	9.72	596	12.70
	Mean	0.67	248.1	11.76	593	14.12
	SD	0.27	64.46	6.76	98.18	1.43
	CV (%)	40.30	25.98	57.48	16.55	10.13
	CD (0.05)	-	-	-	-	-

Estimates of regression of yield through land degradation and rainfall. The treatment wise regressions of soybean yield were calibrated separately with land degradation (LD), rainfall (RF) and both variables together with the data of long term manurial experiments in the study. The regression equations of yield through land degradation variable as given in Table 2 showed that there was a negative influence of land degradation on the yield in all the 9 treatments. The yields significantly decreased over a period of time. The influence or rate of change in the yield was maximum (-107.6) in the plot where FYM 6 t/ha was applied (T8), followed by 60 kg N + 35 kg P/ha with a slope of –103.5 and 40 kg N + 26 kg P/ha (T4) and other the treatments. The predictability (R^2) of soybean yield model based on land degradation ranged from 0.176 for control plot (T1) to 0.381 in the plot where 60 kg N + 35 kg P/ha was applied (T5). The estimate of error (σ) based on regression equations of yield attained with treatments ranged from 430 kg/ha in the plot where 60 kg N + 35 kg P/ha was applied (T5) to 539 kg/ha in the plot where soybean residue 5 t/ha was applied (T9).

Table 7. Seasonal runoff, soil loss and nitrogen loss as influenced by vegetative barriers on different land slopes [Ranade et. al. 1995]

Treatment	Slope %	Runoff mm	Soil loss kg/ha	N loss kg/ha
Check	2.0	115.7	986	23.85
	1.5	85.2	918	15.31
	1.0	87.9	614	10.67
Vetiver Grass	2.0	94.9	662	17.40
	1.5	69.1	453	13.12
	1.0	53.8	465	8.88
Bund+ Cymbopogon	2.0	94.6	567	17.18
	1.5	69.4	509	11.48
	1.0	52.9	474	8.02

Based on the Figure 2 and the regression equations of yield through rainfall as given in Table 3, non-liner influence of rainfall on the yield was observed in all the 9 treatments. The regression coefficients of rainfall were positive for linear term and negative for quadratic term. The linear influence of rainfall on the yield of a treatment as expressed by the regression coefficient of linear rainfall variable ranged from 0.729 in 40 kg N + 26 kg P/ha (T4) to 3.679 in the plot where soybean residue 5 t/ha (T9) was applied. The non-linear influence of rainfall on yield as expressed by the regression coefficient of quadratic rainfall variable ranged from – 0.0006 in 60 kg N + 35 kg P/ha (T5) to – 0.001 in the plots where FYM 6 t/ha + 20 kg N + 13 kg P/ha (T6) and 30 kg N + 26 kg P/ha were applied. The predictability (R^2) of a model based on linear and non-linear variables of rainfall ranged from 0.005 in the plot where 40 kg N + 26 kg P/ha (T4) was applied to 0.138 in control plot (T1). The estimate of error (σ) was minimum in T1 (524 kg/ha), while it was maximum in T7 (607 kg/ha).

Table 8. Integrated effects of tillage, land treatment, green manuring and fertilizer application (after 3 years of experimentation i.e. years 2000-2002) on soil chemical and physical properties on farmers' fields under rainfed cotton system in western M.P. India
(Each values is mean of 10 locations)

Parameters after 3 years of treatments in two soil layers (cm)	Treatment							
	T1- CT + FP		T2- CT+ BBF + RDF		T3- RT+BBF + RDF + GM		T4- RT+ BBF + RDF + GM+S	
	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
Soil pH	7.54	7.56	7.58	7.55	7.57	7.54	7.56	7.53
EC (dS/m)	0.36	0.41	0.38	0.43	0.39	0.42	0.39	0.42
Organic Carbon (%)	0.49	0.43	0.51	0.45	0.62	0.52	0.63	0.53
Available N (kg/ha)	200.0	187.2	204.8	190.8	235.3	207.9	238.9	209.7
Available P (kg/ha)	11.99	9.78	14.04	12.10	21.73	16.03	21.77	17.37
Available K (kg/ha)	481.7	434.7	486.2	427.8	494.6	430.6	495.4	431.1
Available S (kg/ha)	7.50	6.87	7.63	6.65	9.72	7.85	16.25	12.52
Bulk density (Mg/m^3)	1.23	1.31	1.22	1.31	1.19	1.27	1.18	1.27
Porosity (%)	52.80	49.45	52.95	49.53	54.07	51.14	54.68	51.11
Infiltration rate (cm/hr)	3.31		3.43		3.58		3.64	
Hydraulic conductivity of soil (cm/hr)	2.25		2.29		2.42		2.47	
Mean cotton seed yield in kg/ha (CD 5% = 111.42)	975		1063		1188		1370	

T1=Conventional tillage + Flat bed (Farmer's practice) CT+FP, T2=Conventional tillage + Broad bed and furrow + 100% Recommended rate of fertilizers (CT+BBF+RDF), T3=Reduced tillage + BBF+100% RDF + Green manure (RT+BBF+RDF+GM}, T4=Reduced tillage+ BBF+ 100% RDF + GM + Any other deficient nutrient, i.e. sulphur (RT+BBF+RDF+GM+S])

Note: (i) Conventional tillage: One disc ploughing during summer followed by 2 ploughings with deshi plough and planking + ¾ interculture operations with small blade harrow; (ii) Reduced tillage: 1 harrowing + 1 interculture operation + pre-emergence herbicide (no summer ploughing) followed by one ploughing with deshi plough and planking; (iii) Recommended dose of fertilizer (RDF) for cotton consisted of N, P_2O_5, K_2O 80, 60 and 20 kg/ha); (iv) In the treatment 4 gypsum was applied at the rate of 200 kg/ha for meeting S requirement, which was deficient; (v) Two rows of sunhemp were grown in between the rows of cotton which was cut and incorporated in soil after 30 days of planting

Based on the regression models of yield through both land degradation and rainfall variables as given in Table 4, the regression coefficients ranged from –81.006 in FYM 6 t/ha + 20 kg N + 13 kg P/ha (T6) to –121.157 in FYM 6 t/ha

(T8) for land degradation variable, 1.628 in 40 kg N + 26 kg P/ha (T4) to 4.556 in soybean residue 5 t/ha (T9) for linear rainfall variable and –0.001 in T4, T5 and T6 to –0.002 all the treatments for quadratic rainfall variable. The predictability (R^2) ranged from 0.277 in FYM 6 t/ha + 20 kg N + 13 kg P/ha (T6) to 0.507 in FYM 6 t/ha (T8), while the estimate of error (σ) ranged from 463 kg/ha in control (T1) to 546 kg/ha in soybean residue 5 t/ha + 20 kg N + 13 kg P/ha (T7) treatment in the study.

Table 9. Influence of crop residues and farmyard manure on seed yield of soybean and safflower, sustainability index and water use efficiency of crops, mean of 1983–1989 [Sharma 1992]

Treatment	Seed yields (kg/ha)		SYI for Yield		WUE kg/ha per mm	
	Soybean	Safflower	Soybean	Safflower	Soybean	Safflower
N 0 P 0	1117	781	0.39	0.19	2.52	3.46
N 20/40-40	1697 (51.9)	1330 (72.3)	0.60	0.32	3.71	5.62
N 10/20-20	1591 (42.4)	1121 (43.5)	0.55	0.26	3.47	4.94
FYM 6t/ha	1943 (74.0)	1788 (128.9)	0.70	0.43	4.24	7.07
FYM 6 t/ha + N 10/20-20	2044 (83.0)	1987 (154.4)	0.73	0.47	4.50	8.26
Residues 5 t/ha + N 10/20-20	1388 (24.3)	1177 (50.7)	0.35	0.14	3.33	3.28

Note: SYI Sustainable yield index, WUE Water use efficiency and figures in parentheses are percent increase over control

Table 10. Seed yield of unirrigated safflower grown after soybean as influenced by residual effect of FYM, mean of 1983/1984 to 1987/1988 [Sharma, Gupta 1993]

Treatment	Mean seed yield kg/ha		Water use efficiency kg/ha per mm	
	Soybean	Safflower	Soybean	Safflower
N 0 P0	1131	695	2.38	3.71
N 20-40	1628 (+ 43.9%)	1132 (+ 62.9%)	3.32	5.79
N 10-20	1517 (+ 34.1%)	955 (+ 37.4%)	3.08	5.03
6 t/ha FYM alone in rainy season	1808 (+ 59.9%)	1539 (+ 121.4%)	3.66	7.19
6 t/ha FYM + N 10-20	1913 (+ 69.1%)	1692 (+ 143.5%)	3.86	8.70

Estimates of sustainability of nutrient management practices. Based on the procedure developed by Vittal et al. [2002], the estimates of sustainability of nutrient management practices were derived separately using the regression models based on land degradation, rainfall and both variables together and they are given in Table 5. Among the 9 nutrient management treatments tested in the study for soybean, control (T1) was found to have the lowest sustainability, while FYM 6 t/ha + 20 kg N +13 kg P/ha (T6) has the highest sustainability with the regression estimates based on either of the three regression models explored in the study. The estimates of sustainability (η) of nutrient management practices ranged from 0.269 to 0.522 with the estimate of error (σ) based on land degradation variable, 0.253 to 0.506 with σ based on rainfall variable and 0.271 to 0.524 with σ based on the combined regression model of land degradation and rainfall variables. Thus, application of FYM 6 t/ha + 20 kg N + 13 kg P/ha (T6) was found to be highly sustainable and gave a mean soybean yield of 2022 kg/ha in the yield range of 1449 to 3051 kg/ha with a coefficient of variation of 24.1 % under semi-arid vertisols at Indore. This treatment is followed by 60 kg N + 35 kg P/ha (T5) with sustainability of 0.493 using land degradation variable, 0.477 using rainfall variable and 0.495 using both land degradation and rainfall variables. The study also indicated that higher sustainability of any of the nine fertiliser treatments was attained using both land degradation and rainfall variables in the regression model of soybean yield than when either of the two variables were considered.

Table 11. Effect of joint use of tillage and organics on the yield and water use efficiency of soybean grown in rainfed Vertisols

Treatment	Seed yield kg/ha			Water use efficiency kg/ha per mm		Soil chemical properties after 3 seasons				
	1999	2000	2001	2000	2001	OC %	Available nutrients (kg/ha)			
							N	P	K	S
T1- CT+RT+(-OT) + HW	1521	1302	2054	3.66	4.15	0.40	175.5	8.25	602.	6.48
T2- CT+RT+(+OT)+ HW	1577	1405	2130	3.85	4.30	0.39	180.0	8.37	600	6.37
T3- LT+4 t/ha straw +HW	1359	989	2064	2.80	5.22	0.46	184.5	8.50	652	6.85
T4- LT+ 4 t/ha straw +Hb	1200	926	2060	2.64	5.24	0.45	182.5	8.80	612	6.62
T5- LT+ 4 t/ha compost + HW	1457	1108	2058	3.15	5.18	0.47	188.0	10.85	625	8.99
T6- LT+ 4 t/ha compost + Hb	1420	1038	2012	2.74	5.04	0.48	192.0	10.61	627	8.48
T7- LT+ 2 t/ha gliricidia green leaves + Hb	1389	996	2064	2.80	5.21	0.42	189.0	8.55	635	7.24
T8- LT+ 2 t/ha gliricidia green leaves + HW	1425	1055	1977	3.07	4.96	0.43	193.5	8.57	615	7.62
CD 5%	111	104	ns	-	-	-	-	-	-	-

Note: (1) T1– CT+RT+(-OT) + HW; (2) T2– CT+RT+ OT + HW; (3) T3– LT+ 4 t/ha straw + HW; (4) T4– LT+ 4 t/ha straw +Hb; (5) T5– LT+ 4 t/ha compost +HW; (6) T6– LT+ 4 t/ha compost + Hb; (7) T7– LT+ 2 t/ha gliricidia green leaves +Hb; and (8) T8– LT+ 2 t/ha gliricidia green leaves + HW. "CT" is conventional tillage, i.e. one summer cultivation with tractor driven cultivator followed by cultivator operation before sowing of soybean, “OT” is off season tillage, i.e. summer tillage, “LT” is low tillage, i.e. plough planting only, “RF” is recommended dose of fertilizer i.e. N, P, and S 40,26 and 40 kg/ha, respectively to soybean, “Hb” is herbicide application i.e. Treflan as pre-plant incorporation and per suit as post emergence at 25 days after sowing (DAS), HW is hand weeding two times, i.e. at 15 and 30 days after sowing

(RYSUNEK NA CAŁĄ STRONĘ)

Figure 1. Yield of soybean attained with different treatments from 1992 to 2002 at Indore

(RYSUNEK NA CAŁĄ STRONĘ)

Figure 2. Influence of rainfall on soybean yield attained by different treatments at Indore

Changes in the soil organic carbon and available nutrients in the long run. Table 6 presents the data related to changes in the soil organic carbon content and available N, P, K and S status in the surface soil layer after 9 years of experimentation as influenced by different treatments. It is clearly revealed that treatments involving FYM at the rate of 6 t/ha every season and crop residues application at the rate of 5 t/ha initially as surface mulch and its incorporation in subsequent season every year either alone or in combination with reduced level of fertilizer N and P (Treatments at No. 6, 7, 8 and 9 in Table 6) led not only to significant build up of organic carbon content and available nutrients status but also resulted in significant enhancement in the productivity of soybean crop every year as reported in this paper (Tab. 1). On the other hand, there was considerable depletion of organic carbon content and available nutrient status in soil under check plots as well as in plots which received imbalanced nutrition.

The use of residue application/ green manuring, vegetative barriers and land treatments. The data presented in Tables 7 through 11 indicate the beneficial effects of joint use of *in-situ* and *ex-situ* residue application, vegetative barriers, green manuring coupled with cost effective land treatments on soil chemical and physical properties, checking the erosion of carbon and available nutrients from agricultural lands, enhancement in rainfed crop productivity, water use efficiency of crops to a greater extent.

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