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Research Paper

Sustainability of fallow - Indian mustard (*Brassica juncea*) system as influenced by green manure, mustard straw cycling and fertilizer application

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ABSTRACT

A field experiment was conducted for five consecutive years (2005-06 to 2009-10) to evaluate the effect of *dhaincha* (*Sesbania aculeata)* green-manuring (GM), mustard [*Brassica juncea* (L.) Czern & Coss] straw cycling and fertilizers on productivity and sustainability of mustard under fallow–mustard sequence. *Sesbania* (GM) and mustard straw cycling significantly influenced plant height, branches/plant, siliquae/plant, seeds/siliqua as well as seed and oil yields compared to existing fallow-mustard practice. The pooled mustard seed yield registered 42.3% increase due to *Sesbania* (GM) alone and 63.9% due to green manuring + mustard straw cycling. Increase in fertilizer levels from 40 kg N to 80 kg N and 8.7 kg P to 17.4 kg P significantly improved mustard yield attributes and seed and oil yields, while results of K application were inconsistent. The combined application of 80 N + 17.4 P + 33.3 K kg/ha synergistically increased the seed yield by 82.1% over 40 N + 8.7 P kg/ha. Supplementary use of balanced fertilizers (80 kg N: 17.4 kg P: 33.3 kg K) to either of organic treatments, synergistically improved the seed yield at least by three-fourth times. Sustainability yield index, partial factor productivity, production efficiency and incremental benefit cost ratio also showed significant improvement due to *Sesbania* (GM), mustard-straw cycling and judicious fertilizer use.

Key words : Carbon sequestration potential rate, Fallow-mustard, Integrated nutrient management, Mustard straw cycling, *Sesbania* green manure

Indian mustard is cultivated on 5.86 million ha area in India and predominantly in Rajasthan, Uttar Pradesh, Haryana, Madhya Pradesh, Gujarat and West Bengal (DES, 2010). Rajasthan alone contributes 45.5% of total area and 48.6% of the total production (6.41 mt) in the country. Initially, increased use of inorganic fertilizers, clean cultivation practices and high seed replacement ratio improved mustard productivity. However, the technology could not sustain growth in mustard production in last decade as other soil health attributes became limiting in the fragile landscape of semi-arid tropics. The emerging multi-nutrient deficiency has decreased the response of yield to fertilizers (N, P, K) from 14-15 kg seed/unit fertilizer applied in 1960 to 4-5 kg seed/unit fertilizer in 2010. This loss of mustard productivity is attributed to overall deterioration in soil health (Rana and Rana, 2003; Sinsinwar *et al*., 2005). The phenomena could be reversed if inorganic fertilizers are supplemented with organic components (Tiwari *et al.*, 2002; Thakur *et al.*, 2011).

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Due to poor fodder and fuel value, mustard straw is usually burnt to clear the fields but if incorporated into the soil has enormous potential to improve soil health. Additionally, green manuring during rainy season is advocated for improvement in mustard productivity of fallow-mustard sequence (Kumar *et al.*, 1995). But the existing informations lack in overall impact of organic incorporation on growth, productivity and quality of mustard on a long-term basis. Therefore, the present study was carried out to evaluate the effects of mustard straw and green manure on mustard productivity and sustainability.

MATERIALS AND METHODS

A field experiment was conducted for five consecutive years at Directorate of Rapeseed-Mustard Research, Bharatpur from 2004-05 to 2009-10 on clay loam soil with 8.1 pH, 2.6 g/kg organic carbon, 95.4 kg $KMnO_4$ oxidizable N/ha, 5.4 kg 0.5N $NaHCO_3$ extractable P/ha and 267 kg 1.0 N NH_4OAc exchangeable K/ha.. The experiment was conducted in split-plot design with three replications. The main-plot received three combinations of organic sources *viz*., fallow-mustard (control), *Sesbania* (GM) - mustard and *Sesbania* (GM) + mustard straw @ 2.5 t/ha -

mustard, while eight combinations of N (40, 80 kg/ha), P (8.7 and 17.4 kg/ha) and K (0 and 33.3 kg/ha) were assigned to sub–plots. For comparison of treatments the reference group received fallow-mustard (control) of organic treatments and $N_{40}P_{8.7}K_0$ of fertility levels.

Indian mustard, *'Rohini'* was sown in the first fortnight of October during all the years. The seeds were sown at 5 kg/ha at 30 cm x 10 cm spacing at a depth of 5 cm with the help of manual plough. The plant to plant distance was maintained at 10-15 cm by thinning at 25 DAS. Half dose of N through urea and full dose of P as SSP and K as murate of potash were applied basal at the time of land preparation, whereas the remaining N in the form of urea was top-dressed after first irrigation. The above ground mustard straw (C:N ratio 70-80:1) after threshing was incorporated on the dry weight basis into the soil one month before the sowing of green manure crop. *Sesbania aculeata* (C:N ratio 19:1) as a green manure crop was sown in the first week of July every year. About 45 days old succulent green manure crop was ploughed down and incorporated into the soil for decomposition. On an average, mustard straw 2.5 t/ha and *Sesbania* 4.1 t/ha on dry weight basis added 9.5 and 96.4 kg N/ha, respectively.

Sustainable yield index (SYI): It is the ratio of minimum assured seed yield to maximum observed yield (Singh *et al*., 1990) and mathematically described as:

$$SYI = (Y_a - \sigma)/Y_m \quad ... (1)$$

where Y_a is mean yield, σ is the standard deviation of yield, and Y_m is the maximum yield obtained under a set of management practices. The nearness of SYI to 1.00 implies the closeness to an ideal condition that can sustain maximum crop yield over the years, while deviation from 1.0 indicates the losses to sustainability (Bhindhu and Gaikwad, 1998).

Partial factor productivity (PFP): The influence of the combined effect of all nutrients on seed yield is quantified through partial factor productivity (PFP). It is a ratio of seed yield to applied nutrient and estimated as an index to efficiency of individual input (Cassman *et al.*, 1996). Here, total N, P and K supplied through inorganic or organic sources as per treatment was used as denominator to estimate PFP.

The Carbon sequestration potential (CSP): It is average rate of change in mass of soil organic carbon (MSOC) and expressed as Mg/ha/year (Bhattacharya *et al.*, 2010). The MSOC was calculated as:

$$MSOC = “\Sigma OCi \times \rho_i \times d_i \quad ... (2)$$

where MSOC is mass of SOC (Mg/ha), SOC_i is soil organic C concentration, ρ is bulk density (Mg/m) and d is thickness (cm) of i^{th} horizon. Being arable land, only plough layer (0-15 cm) was used to estimate the CSP of various treatments.

Production efficiency (PE): It represents the increase in seed yield on a daily basis and calculated by dividing total mustard seed production/ ha in a sequence with total duration of the crops in a sequence (Tomar and Tiwari, 1990).

The overall profit and the incremental B: C ratio (IBCR) from additional inputs is the ultimate concern among the growers. The cost of cultivation of mustard, excluding that of nutrient input, was kept similar in all the treatments. Therefore, the ratio of the price of yield to the cost of nutrient inputs may be referred to as the IBCR of treatments. Mathematically can be expressed as

$$B{:}\ C\ ratio= (\Delta Y \times P_y)/ (F_n \times P_n) \quad ... (3)$$

where ΔY is the increase in seed yield due to main or sub plot treatments over respective checks, P_y the price of mustard seed, F_n the amount of nutrient applied, and P_n the cost of the applied nutrient input.

The standard analysis of variance (ANOVA) test was performed using SPSS 17.0 to compare the treatment means for each year separately. Treatment means were compared ($P \leq 0.05$) using least significant difference (LSD). The year variance over years was estimated homogeneously by performing Bartlett χ^2 test and hence results of pooled analysis are presented here to draw logical inferences.

RESULTS AND DISCUSSION

Yield attributes

Organic treatments and fertility levels significantly influenced the yield attributes of mustard (Table 1). *Sesbania* (GM) significantly increased the number of branches/plant by 35.4% over fallow-mustard (control). Further addition of mustard straw @ 2.5 t/ha significantly improved the branches/plant by 11.1% over *Sesbania* green manuring and 50.5% over fallow-mustard. The organic supplements through green manure and mustard straw over the years might improved the physico-chemical properties of soil which resulted in better plant growth, optimum biomass partitioning, larger sink base and ultimately better yield attributes as also reported earlier by Pasricha *et al.* (1988) and Kumar *et al.* (1995) in rapeseed. Almost similar trend was observed in plant height, siliquae/plant and seeds/siliqua with green manuring, however, the increase in attributes due to mustard straw was statistically at par with green manuring. The 1,000-seed-weight was not influenced significantly due to organic treatment.

Various combinations of N, P and K significantly increased the number of siliquae/plant, which is the main yield contributing character of Indian mustard. The higher

Table 1. Effect of organic manures and fertility levels on growth, yield attributes, oil content, sustainability yield index (SYI), production efficiency (PE), carbon seques tration potential rate (CSPR), partial factor productivity (PFP) and IBCR of Indian mustard (Pooled data of five years)

Treatment	Plant height (cm)	Branches/ plant	Siliquae/ plant	Seeds/ siliqua	1,000-seed wt. (g)	Oil content (%)	Oil yield (t/ha)	SYI	PE (kg/ha/ day)	CSPR (Mg/ha/ yr)	PFP (kg grain/ kg nutrient)	IBC Ratio
Organic sources												
Fallow- mustard (control)	174.2	9.3	174.4	13.4	5.3	42.4	0.57	0.36	8.6	0.124	-	-
Sesbania (GM) - mustard	185.4	12.6	187.8	14.5	5.6	41.6	0.79	0.54	12.3	0.256	7.9	6.9
Sesbania (GM) + mustard straw @ 2.5 t/ha - mustard	192.5	14.0	192.8	14.8	5.9	40.9	0.89	0.63	14.1	0.373	7.1	3.0
SEm±	2.3	0.3	3.1	0.2	0.2	0.1	0.02	0.01	0.37	0.04	0.4	0.3
CD (P=0.05)	6.7	0.9	9.6	0.6	NS	0.4	0.04	0.04	1.10	0.116	NS	0.8
Fertility level (kg/ha)												
$N_{40}P_{8.7}K_0$	174.9	10.4	155.7	13.8	5.0	42.0	0.54	0.34	8.4	0.164	26.6	-
$N_{40}P_{8.7}K_{33.3}$	177.0	11.0	171.2	14.0	5.2	42.1	0.59	0.38	9.1	0.176	17.2	5.8
$N_{40}P_{17.4}K_0$	180.1	11.8	179.7	14.4	5.3	42.3	0.67	0.43	10.2	0.195	27.4	10.2
$N_{40}P_{17.4}K_{33.3}$	181.5	11.7	183.6	14.1	5.5	42.0	0.70	0.46	10.8	0.211	18.4	4.2
$N_{80}P_{8.7}K_0$	186.7	12.3	193.9	14.0	5.8	41.0	0.79	0.57	12.4	0.277	21.7	17.5
$N_{80}P_{8.7}K_{33.3}$	187.9	12.3	197.1	14.6	5.9	41.3	0.82	0.58	12.8	0.324	16.3	3.0
$N_{80}P_{17.4}K_0$	191.6	13.0	198.7	14.7	5.9	41.1	0.92	0.66	14.5	0.331	23.1	14.8
$N_{80}P_{17.4}K_{33.3}$	192.5	13.3	200.2	14.5	5.9	41.3	0.97	0.67	15.2	0.333	18.0	4.2
SEm±	2.7	0.4	5.9	0.3	0.2	0.3	0.01	0.02	0.5	0.056	1.0	0.3
CD (P=0.05)	7.8	1.0	17.1	0.9	0.7	0.9	0.04	0.05	1.4	0.157	2.84	0.9

doses of N and P resulted in 14.4 and 6.2% increase in siliquae/plant and combined application ($N_{80}P_{17.4}K_{33.3}$) synergistically increased the attribute by 30% over lowest dose ($N_{40}P_{8.7}K_0$). Keeping levels of other two nutrients same, higher N levels significantly increased siliquae/plant. The effect of K was non-significant, while the effect of P was inconsistent. The highest number of siliquae/plant was recorded with $N_{80}P_{17.4}K_{33.3}$, but was at par with the same fertility level without potassium application. Almost similar trend was observed in plant height, branches/ plant and 1,000 seed-weight.

Seed yield

Over the years, the seed yield of mustard was significantly influenced due to inclusion of organic treatments (Fig. 1). The pooled yield data of five years indicated that the *Sesbania* (GM) significantly increased mustard seed yield by 41.8% over control. Supplementary incorporation of mustard straw @ 2.5 t/ha increased the seed yield by 15.3% over *Sesbania* (GM) alone and 63.9% over control. This is attributed to the gradual build up of major, secondary and micronutrients in rhizosphere and thus balanced nutrient supply to the plants, improved soil conditions through higher microbial biomass and more stable organic carbon fractions resulting better growth, development and higher yield (Sinsinwar *et al*., 2005). *Sesbania* (GM) recorded almost a uniform increase in seed yield over control throughout the study period. However, the gap in yield between *Sesbania*

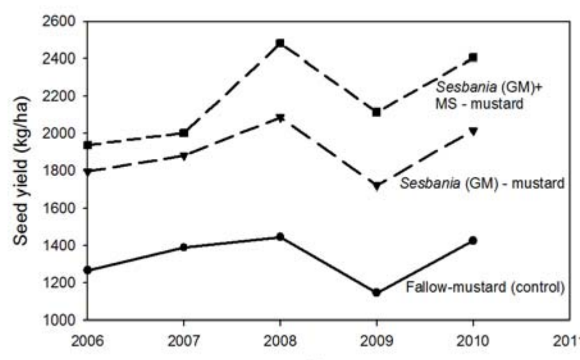

Fig 1. Effect of organic treatments on seed yield of mustard over the years

(GM) and *Sesbania* (GM) + mustard straw (MS) treatments widened with time.

Application of different fertility levels significantly influenced seed yield of mustard during all the five years. In general, increase in N dose from 40 to 80 kg/ ha increased seed yield by 43.2%. The increase in seed yield due to enhanced P rate from 8.7 to 17.4 kg/

ha was 18.9%, while it was just 5.4% due to K application. The combined application of $N_{80}P_{17.4}K_{33.3}$ synergistically increased the seed yield by 82.1% over the lowest fertility level. Keeping levels of other two nutrients same, higher level of N as well as P individually increased the mustard yield significantly, while the effect of K was inconsistent.

Seed yield of mustard was significantly influenced by interaction of organic sources and fertility levels (Table 2). At fallow-mustard (control), the seed yield was increased by 26.6% when P level was enhanced to 17.4 kg P/ha and by 56.4% when N level was enhanced to 80 kg N/ha from the reference level of $N_{40}P_{8.7}K_{0.}$ And synergistically higher seed yield was recorded when higher level of both P and N were applied. Application of K marginally improved the seed yield. At *Sesbania* (GM) treatments significant increase in seed yield over reference fertility level ($N_{40}P_{8.7}K_0$) was recorded when combined higher level of P (17.4 kg/ha) and K (33.3 kg/ha) were applied. However, enhancing N level from 40 to 80 kg/ha significantly increased the seed yield by 40.3% over reference level ($N_{40}P_{8.7}K_0$) and by 22.4% over $N_{40}P_{17.4}K_{33.3.}$ Over all maximum yield (2.5t/ha) was recorded when $N_{80}P_{17.4}K_{33.3}$ was applied to Sesbania green manured plots, but the effect remained at par with $N_{80}P_{17.4}K_{0.}$ Almost similar effect of fertility levels were recorded in plots with Sesbania (GM) + mustard straw, except the seed yield at $N_{80}P_{17.4}K_{33.3}$ was significantly higher by 6.6% over $N_{80}P_{17.4}K_{0.}$ Overall significant maximum seed yield was recorded when Sesbania (GM) + mustard straw was supplemented with fertility level of $N_{80}P_{17.4}K_{33.3.}$ The soils of the region are medium in available K and are able to meet crop demand at low productivity levels of fallow-mustard (control) and resulted into non-significant effect of applied K. However at higher productivity levels the available soil K was unable to match crop demand and thus K application showed a positive response at *Sesbania* (GM) and significantly higher response at *Sesbania* (GM) + mustard straw treatment. Synergistically, the chemical fertilizers facilitate the quick decomposition and faster utilization of the organic sources in the form of *Sesbania* (GM) and mustard straw by checking nitrate depression in the soil, hence, higher yield levels were recorded over fallow-mustard during five year period.

Oil content and oil yield

The oil content was significantly decreased due to *Sesbania* (GM) and successive addition of mustard straw over control and application of 80 kg N/ha over 40 kg N/ha (Table 1). The highest oil content was obtained in fallow-mustard. Nitrogen plays an important role in protein balance, oil biosynthesis and maintaining oil: protein ratio among oilseed crops (Tripathy and Sawhney, 1989). More available nitrogen with supplementary organics and 80 kg N/ha enhance degradation of carbohydrates (tricarboxylic cycle) to acetyl CoA, thereby processes of reductive amination and transamination to produce more amino acids (Satyanarayan *et al.*, 1986) causing increased seed protein content with corresponding decrease in seed oil content (Hussain *et al*., 1998).

The oil yield recorded almost a reverse trend to oil content. *Sesbania* (GM) significantly increased oil yield by 38.5% over control. Supplementary addition of mustard straw increased the oil yield by 12.7% over *Sesbania* (GM) and 56.1% over control. Similarly, successive increase in fertility levels of N and P significantly increased the oil yield over lower levels of respective nutrients. However, potassium significantly increased oil yield only when higher level of N+P was applied ($N_{80}P_{18.7}K_{33.3}$). Overall, fertility treatment $N_{80}P_{8.7}K_{33.3}$ increased the oil yield by 79.6% over $N_{40}P_{8.7}K_{0.}$ Oil yield is the function of oil content and seed yield. Since variation in oil content has genetic and biochemical limitations, the oil yield is

Table 2. Seed yield of mustard (t/ha) as influenced by organic manures and fertility levels

Organic sources/Fertility level (kg/ha)	Fallow – mustard (control)	*Sesbania* (GM) - mustard	*Sesbania* (GM) + @ mustard straw 2.5 t/ha - mustard	Mean
$N_{40}P_{8.7}K_0$	0.94	1.44	1.55	1.31
$N_{40}P_{8.7}K_{33.3}$	0.99	1.53	1.70	1.41
$N_{40}P_{17.4}K_0$	1.19	1.61	1.93	1.58
$N_{40}P_{17.4}K_{33.3}$	1.34	1.65	2.02	1.67
$N_{80}P_{8.7}K_0$	1.47	2.02	2.29	1.93
$N_{80}P_{8.7}K_{33.3}$	1.48	2.09	2.39	1.99
$N_{80}P_{17.4}K_0$	1.64	2.37	2.74	2.25
$N_{80}P_{17.4}K_{33.3}$	1.67	2.50	2.92	2.36
Mean1.34	1.90	2.19	-	
Organics	Fertility levels	Organics × fertility levels		
SEm±	0.04	0.03	0.06	
CD (P=0.05)	0.14	0.08	0.18	

more influenced by seed yield and thus followed almost trend similar to seed yield.

Sustainability yield index (SYI)

Over the study period organic treatments as well as inorganic fertilizer treatments significantly influenced the SYI (Table 1). *Sesbania* (GM) significantly increased SYI by 50.5% over control. Further addition of mustard straw @ 2.5 t/ha increased the SYI by 16.7% over *Sesbania* (GM) and 75.0% over control. Similarly, successive improvement in fertilizer level increased the SYI and significantly higher values over control ($N_{40}P_{8.7}K_0$) were obtained when higher levels of either N (80 kg/ha) or P (17.4 kg/ha) was applied. Overall fertility treatment $N_{80}P_{17.4}K_{33.3}$ increased the SYI by 97.1 % over control ($N_{40}P_{8.7}K_0$).

Production efficiency (PE)

Production efficiency increased due to growing *Sesbania* green manure with or without mustard straw incorporation. Organic supplements in soil for five years improved the nutrient supplying capacity of the soil and hence increased PE. A higher PE was obtained when *Sesbania* (GM) is supplemented with mustard straw incorporation. The higher metabolizable carbon and N in green manure and crop straw supports increased root biomass and root absorption surfaces (Hao *et. al*., 2008). A gradual increase in the PE was noticed due to the application of various fertilizers as well (Table 1). Significantly higher PE was obtained when $N_{80}P_{18.7}K_{33.3}$ was applied over $N_{80}P_{18.7}K_0$. Fertilizer application helps the crop in quick utilization of the readily available nutrients resulting in higher growth and dry matter accumulation which increases the per day productivity of mustard. Adequate N, P and K supply to mustard improved the integrity of plant structure and key physiological processes such as light interception by chlorophyll, energy for carbohydrate buildup and enhanced hydraulic conductivity of the root cortical cells, thereby improving the yield (Makino *et al*., 1992).

Partial factor productivity (PFP)

The amount of total nutrients applied through *Sesbania* (GM) + MS incorporation was more than *Sesbania* (GM) alone, thus per unit increment in seed yield decreased and so also the PFP. The PFP decreased by 11.6% due to increased N levels (80 kg N/ha) and by 29.3% due to K level (33.3 kg K/ha) indicating poor rate of utilization of N and K by the crop at higher levels. However, the PFP increased by 6.6% due to increase in P level to 18.7 kg/ha, indicating efficient translocation of nutrient and photosynthates to the seeds. It is also due to the curvilinear return to the conversion of plant nutrients to seed as yield approaches the ceiling at higher levels of nutrients (Cassman *et. al*., 1996).

Table 3. Effect of organic manures and chemical fertilizers on soil properties after mustard harvest in fifth year

Treatment	$KMnO_4$ oxidizable N (kg/ha)	Olsen-P (kg/ha)	Available K (kg/ha)
Organic sources			
Fallow- mustard (control)	74	7	221
Sesbania (GM) - mustard	100	9	245
Sesbania (GM) + mustard straw @ 2.5 t/ha - mustard	119	9	259
SEm ±	0.7	0.1	1.7
CD (P=0.05)	2.2	0.2	5.0
Fertility level (kg/ha)			
$N_{40}P_{8.7}K_0$	79	8	225
$N_{40}P_{8.7}K_{33.3}$	81	8	236
$N_{40}P_{17.4}K_0$	86	8	231
$N_{40}P_{17.4}K_{33.3}$	90	8	241
$N_{80}P_{8.7}K_0$	104	9	243
$N_{80}P_{8.7}K_{33.3}$	111	9	252
$N_{80}P_{17.4}K_0$	113	9	249
$N_{80}P_{17.4}K_{33.3}$	116	9	257
SEm±	1.4	0.2	1.5
CD (P=0.05)	4.0	0.6	4.0

Soil fertility

Sesbania (GM) significantly increased available N in plough layer by 35% over control after five years of experimentation (Table 3). The supplementary mustard straw increased available N by 18.9% over *Sesbania* (GM) and 60.6% over control. Almost similar trend was observed for available P and K status. Over the study period, the available N content decreased by 22.5% in control and increased by 4.6% due to *Sesbania* (GM) and 24.4% *Sesbania* (GM) + mustard straw. A net build up of available P and net depletion in available K was observed in all main plots. The organic manures are slower but gradual source of plant available nutrients in the soil. Significant build up of N and P is also attributed to the addition and retention of nutrients and their regulated release due to periodic mineralization of the straw. Increasing fertility levels caused corresponding improvement in available nitrogen, phosphorus and potassium after five years of experimentation. However, compared to initial test values, a net build up in available P and net depletion in available K was observed at all fertility levels. While net available N level increased at higher N level treatments (N_{80}) only. The N and P status of the soil increased with increasing fertility level due to higher availability and carry over effect from the applied source (Kumar and Goh, 2000; Shafi *et al*., 2007).

Economics

Various organic sources and fertilizer levels significantly improved the net return margins over the check treatments. Each unit cost invested in *Sesbania* (GM) returned 6.87 units over check (fallow-mustard) system due to improvement in mustard productivity. However, additional mustard straw cycling reduced the IBCR to 2.99 only. The benefits due to mustard straw incorporation are more in terms of soil health (physico-chemical and biological properties), which sustain the soil productivity in long run. Increase in IBCR by 10.17 due to increased P level (8.7 to 17.4 kg P/ha), 17.47 due to increased N level (40 to 80 kg N/ha) and 14.78 due to combined increase in both N and P levels was estimated. The application of K fertilizer significantly reduced the net margin (IBCR 3.03 to 5.77) at all combinations of N and P. The lower response of K application in the K dominant illitic soils of semi-arid regions was observed hence was economically less beneficial over N and P application. Although, the highest yield was obtained with $N_{80}P_{17.4}K_{33.3}$, but $N_{80}P_{8.7}K_0$ was found to be most beneficial treatment.

It is concluded from the study that *Sesbania* as green manure and incorporation of mustard straw improved carbon sequestration potential of the soil, better partial factor productivity and production efficiency. Supplementary fertilizer at balanced level ($N_{80}P_{17.4}K_{33.3}$) synergistically complements the productivity indices. This integrated approach of organics and balanced fertilizers finally helps in realization of sustainable mustard production with higher economic returns on a long term basis under semi arid region of Rajasthan.

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