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Enhancing resource conservation, soil health and productivity of mustard through green manuring in fallow – mustard cropping sequence

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ABSTRACT

A field experiment was conducted at research centre Kota to identify the suitable green manure crop for fallow–mustard sequence to conserve resources, improve soil fertility, enhance productivity and profitability of the fallow–mustard system during 2008–09 to 2010–11. The experiment was laid out in a split plot design with three replications. The main plot involved four green manuring treatments while subplots comprised of four N levels. The three years average data indicated that runoff and soil loss was reduced by 24–43% and 21–42%, respectively over control. An average amount of about 2.0–3.3 t ha^{-1} dry biomass of green manure crops was incorporated into the soil, which recycled an average amount of 46.6–94.6 kg N ha^{-1} over three years. Green manuring also enhanced the soil organic carbon (SOC) and available N, P, and K content into the soil. The seed yield of mustard increased by 40%, 52.8% and 75% under *in–situ* green manuring of cluster bean, sunhemp and sesbania, respectively as compared to without green manuring. A progressive increase in the yield of mustard was also recorded with the increasing N levels and the maximum yield was recorded with 45 kg N ha^{-1}. Similarly, water use efficiency (WUE) was also positively influenced by different green manure treatments and N levels. Green manuring and N application were found economically viable over control in all the three years. Among the three green manure crops, sesbania was found to be most effective in reducing runoff, soil loss, and enhancing soil fertility, crop productivity and profitability in the rainfed region of south–eastern Rajasthan.

1. INTRODUCTION

Mustard (*Brassica juncea* L.) is an important *rabi* season oilseed crop cultivated in about 6 lakh ha under rainfed / irrigated conditions in south–eastern Rajasthan. It is raised after *kharif* fallowing and its sowing is generally completed by 1st week of October to escape aphid infestation on the crop. Nearly 56% of arable lands are under rainfed farming in south–eastern Rajasthan where fallow–mustard is a prominent land–use system. A productivity loss of 13.4 Mt due to soil erosion in rainfed regions of India has been reported by Sharda *et al.* (2010). The inclusion of short–duration green manure crops in fallow mustard sequence can reduce erosion hazards and improve soil fertility which consequently enhances the productivity of rainfed mustard. Hence, there is a good scope of introducing a green manure crop during the fallow period to reduce runoff and soil loss and improve soil fertility. Further, soil organic carbon (SOC) is a vital component for sustaining soil health and crop productivity. Green manuring is a potential alternative or supplemental agronomic strategy to sustain crop production, build–up SOC and thus, improve soil health in the long–term while minimizing the use of external chemical fertilizers. Moreover, *in–situ* green manuring offers a viable and sustainable solution to the constraints related to crop production and soil fertility in rainfed regions. Thus *in–situ* green manuring not only adds essential plant nutrients to the soil but also improves the physical, chemical and biological properties of soil (Kumar and Goh, 2000). *In–situ* green manuring of sunhemp (*Crotalaria juncea* L.) has been proved to sustain soil fertility through reduced runoff and soil loss (Singh *et al.,* 2011, 2016). Sesbania (*Sesbania aculeata* Poir) green manuring during *kharif* season followed by mustard cultivation enhanced the crop growth, agronomic yields and net returns due to reduced soil erosion and weeds infestation, increased conservation and

efficient utilization of rainwater, and improved soil fertility compared with fallow− mustard crop rotation (Singh *et al.,* 2019). Hence, it was hypothesized that green manuring would help in improving crop production through effective rainwater utilization and better resource conservation. Keeping this in view, the study was conducted with a view to identify a suitable green manure crop which can be successfully fit in fallow−mustard sequence and can conserve the natural resource, improve soil fertility, enhance agronomic yield and net income of the farmers in the rainfed agro−ecosystem of south−eastern Rajasthan.

2. MATERIALS AND METHODS

The study was carried out at the Research Farm of ICAR−Indian Institute of Soil and Water Conservation (IISWC), Research Centre, Kota, Rajasthan (25º11'N latitudes and 75º51'E longitudes with 256.9 m above mean sea level) to identify suitable green manure crop for fallow−mustard sequence for resource conservation and soil fertility improvement and to study the effect of green manuring on the yield of mustard and economics of the system during 2008−09 to 2010−11. The climate of the region is semi−arid with an average annual rainfall of 740 mm of which 90% occurs from mid−June to September. The mean maximum temperature (41.9°C) was recorded in May and a mean minimum (6.9°C) in January. The soils of the region are clay loam to clay in texture (*typic Chromusterts*) with brown to dark greyish brown in colour, with pH ranging from 7.4–8.4, bulk density 1.20–1.39, and moisture holding capacity of 10.1–16.8%. The initial fertility status of the experimental site is given in Table 1. The field experiment was laid out in a split plot design with three replications. The main plot consists of four green manuring treatments (GM_0 − no green manure crop, GM_1−Sunnhemp (*Crotalaria juncea* L), GM_2 − Sesbania (*Sesbania aculeata* Poir) and GM_3 − Cluster bean (*Cyamopsis tetragonolaoba* L.) and four N levels (N_0 − control / no N application, N_1 − 15, N_2 − 30 and N_3 − 45 kg ha^{-1}) in subplots. The net plot size was 15 m × 4.5 m. The green manuring crops were sown using a seed rate of 40−45 kg ha^{-1} in the first fortnight of July every year during the experimental period and turned into the soil at maximum canopy cover after 35−45 days of sowing in the third week of August every year from 2008−2011. The sowing of mustard was done in the month of October every year with a seed rate of 6 kg ha^{-1}. The harvesting of mustard was done by manually at 10−12% moisture content in the month of February−March every year.

Table: 1
Initial fertility status of the experimental field

Soil fertility parameters	Soil depth (cm)	
	0−15	15−30
pH	7.43	7.36
EC	0.19	0.16
OC (%)	0.36	0.28
N (kg ha^{-1})	190	155
P (kg ha^{-1})	13.0	10.40
K (kg ha^{-1})	579	451

The soil pH and electrical conductivity (EC) were measured by using a soil water suspension ratio of 1:2.5 (Jackson, 1973). The SOC was determined using the method described by Walkley and Black (1934). The soil available N was assessed by alkaline permanganate ($KMnO_4$) method (Subbiah and Asija, 1956), available P extracted with 0.5 M sodium bicarbonate (pH 8.5) reagent (Olsen *et al.,* 1954) and available K extracted with 1 N neutral ammonium acetate (Jackson, 1973). Runoff and soil loss data were collected during the rainy season (July− September) for all the three years from 2008 to 2011. The cost of cultivation was computed based on mustard seed yield and cost incurred on inputs *viz.,* cost of seed, fertilizers, human labour, sowing−harvesting operations, *etc.* Net return was assessed by subtracting total cost from gross returns and benefit:cost (B:C) ratio was calculated by dividing net return by the total cost of cultivation. Analysis of variance (ANOVA) was used to test the statistically significant differences between different treatments at a 5% probability (p<0.05) level (Gomez and Gomez, 1984).

3. RESULTS AND DISCUSSION

The monsoon season rainfall varied from 344 mm to 447 mm with an average of 392 mm during 3 years of experimental period. About 15.6% of the rainfall was lost through surface runoff from fallow plots without green manure which reduced to 11.9, 10.1, and 8.9%, respectively under cluster bean, sunhemp and sesbania green manure crops (Table 2). Among the green manure crops, the performance of sesbania was better than sunnhemp and cluster bean. Similarly, the plot without green manure crop recorded maximum soil loss (1.9 t ha^{-1}). The three years pooled data indicate maximum runoff in cluster bean green manured plot as compared to sesbania and sunhemp. The mean data indicated that sesbania added 3.3 t ha^{-1} dry biomass compared to 2.5 and 2.0 t ha^{-1} of sunnhemp and cluster bean, respectively. Also, the three years pooled amount of N recycled through green manuring was highest in sesbania (94.6 kg ha^{-1}), followed by sunhemp (58.4 kg ha^{-1}) and clusterbean (46.6 kg ha^{-1}). Singh *et al.* (2017) reported reduced runoff and soil loss in the plots of sunhemp with 50% N through inorganic fertilizers over control. The fast and vigorous growth of green manure crops creates an umbrella against the beating action of falling raindrops, which helps in reducing runoff and prevents detachment of soil particles and loss of plant nutrients (Sharda *et al.,* 1999; Ghosh *et al.,* 2016). Further, the increased supply of organic carbon improves the soil structure and enhances infiltration rate of

Table: 2
Effect of green manuring on runoff, soil loss, green manure biomass production and N recycling

Treatment	2008−09	2009−10	2010−11	3−years pooled
Rainfall (mm)	383	447.1	344.4	391.5
Runoff (%)				
GM_0	11.3	25.9	9.5	15.6
GM_1	9.9	14.7	5.6	10.1
GM_2	9.8	11.2	5.8	8.9
GM_3	10.5	17.8	7.3	11.9
Average	10.4	17.4	7.1	11.6
Soil loss (t ha^{-1})				
GM_0	1.48	3.16	1.11	1.9
GM_1	1.35	1.42	0.98	1.3
GM_2	1.26	1.21	0.95	1.1
GM_3	1.41	1.95	1.2	1.5
Average	1.4	1.9	1.1	1.5
GM dry biomass (t ha^{-1})				
GM_0	–	–	–	–
GM_1	2.22	2.31	3.12	2.5
GM_2	3.94	2.42	3.39	3.3
GM_3	1.43	1.98	2.46	2.0
Average	2.5	2.2	3.0	2.6
N recycled (kg ha^{-1})				
Gm_0	–	–	–	–
GM_1 (2.29% N dry wt. basis)	50.83	52.89	71.45	58.4
GM_2 (2.91% N dry wt. basis)	114.65	70.42	98.65	94.6
GM_3 (2.38% N dry wt. basis)	34.03	47.12	58.55	46.6
Average	84.2	48.0	76.2	66.5

soil, which in turn reduces the runoff and soil loss (Bhattacharya *et al.,* 2008; Sharma and Banik, 2014).

The continuous green manuring for three years had a significant positive impact on soil fertility status (Table 3). Sesbania green manuring recorded the maximum organic carbon (0.45%) in 2008−09, while sunhemp green manuring was found better in increasing organic carbon during 2009−10 and 2010−11. The maximum soil available N, P, and K was found in sunhemp green manuring followed by sesbania and clusterbean in all the three years. The three years pooled data also indicated the highest SOC, N, P, and K in sunhemp green manuring followed by sesbania and clusterbean. Shekhawat *et al.* (2018) reported 50% and 46% higher SOC in the 4 years sesbania−mustard and cluster bean−mustard cropping system, respectively over fallow−mustard crop rotation. Further, the increased biomass incorporation in the green manure−mustard system enhanced the mass of SOC by 50.8%, 50.6%, and 48.6% at 0–15 cm, 15–30 cm, and 30–45 cm, respectively, as compared to the fallow−mustard system. Green manure crops decompose quickly and upon decomposition enrich the soil with

Table: 3
Effect of different green manure crops on soil fertility status before sowing of mustard crop

Treatment	Organic carbon (%)	Available nutrients (kg ha^{-1})		
		N	P	K
Soil fertility status during 2008−09				
GM_0	0.39	241.5	22.3	689
GM_1	0.42	319.9	28.1	654
GM_2	0.45	279.3	25.6	644
GM_3	0.40	260.3	23.2	607
Soil fertility status during 2009−10				
GM_0	0.38	150.5	11.9	534
GM_1	0.42	263.4	17.5	645
GM_2	0.41	175.6	15.2	613
GM_3	0.39	163.1	13.5	527
Soil fertility status during 2010−11				
GM_0	0.32	245.2	12.3	481
GM_1	0.43	317.1	14.9	529
GM_2	0.38	298.8	13.2	543
GM_3	0.36	258.3	12.7	558
3−years pooled				
GM_0	0.36	212.4	15.5	568.0
GM_1	0.42	300.1	20.2	609.3
GM_2	0.41	251.2	18.0	600.0
GM_3	0.38	227.2	16.5	564.0

essential plant nutrients (add up to 38 kg N ha^{-1}), improve SOC and recycles nutrients into the soil. Thus, the improved soil fertility contributes to increased yield attributes and productivity of mustard (Aulakh and Pasricha, 1997; Shekhawat *et al.,* 2018). Singh *et al.* (2017) also documented increased SOC and available N, P and K in the plots of green manure with 50% N through inorganic fertilizers over control.

All the green manure crops had a significant positive effect on mustard seed yield. Averaged over 3 years mustard yield increased by 40%, 52.8% and 75% under green manuring of cluster bean, sunnhemp and sesbania, respectively over the without green manuring (Table 4). Increased seed yield of mustard under sesbania green manuring may be attributed to its higher N content and SOC addition in the soil through its biomass incorporation (Shekhawat *et al.,* 2018). The yield of mustard progressively increased with N levels and maximum yield was recorded with 45 kg N ha^{-1}. Sesbania green manure without N application produced a significantly higher yield than control with 45 kg N ha^{-1}. The yield under sunnhemp green manuring was at par with 45 kg N ha^{-1} under control whereas, the yield under cluster bean without N was comparable under control with 30 kg N ha^{-1}. Singh *et al.* (2019) reported 19−48% increased mustard seed yield in the sesbania−mustard cropping system as compared to the fallow−mustard crop sequence. Similar results were also reported by Narayan and Biswas (2012)

Table: 4
Interaction effect of different green manure crops and N levels on seed yield (kg ha^{-1}) of mustard during 2008−09 to 2010−11

Treatment	GM_0	GM_1	GM_2	GM_3	Average
Seed yield during 2008−09					
N_0	750	1325	1690	1350	1278.8
N_1	990	1590	1830	1610	1505.0
N_2	1150	1740	1910	1730	1632.5
N_3	1290	1830	1930	1820	1717.5
Average	1045	1621	1840	1628	1533.4
Seed yield during 2009−10					
N_0	524	981	1238	687	857.5
N_1	718	1126	1346	935	1031.3
N_2	834	1253	1370	1092	1137.3
N_3	942	1290	1381	1207	1205.0
Average	755	1163	1334	980	1057.8
Seed yield during 2010−11					
N_0	597	1073	1334	760	941
N_1	817	1212	1450	1007	1121.5
N_2	905	1366	1472	1232	1243.8
N_3	1033	1332	1510	1336	1302.8
Average	838	1246	1442	1084	1152.3
3−years pooled	879.2	1343.2	1538.5	1230.5	1247.8

Table: 5
Effect of different green manure crops and N levels on WUE (kg ha^{-1}mm^{-1}) of mustard

Treatment	GM_0	GM_1	GM_2	GM_3	Average
WUE during 2008−09					
N_0	7.5	12.5	14.7	13.5	12.1
N_1	9.4	13.8	16.0	15.2	13.6
N_2	11.2	16.4	16.7	16.3	15.2
N_3	11.9	15.8	16.7	17.0	15.4
Average	10.0	14.6	16.0	15.5	14.0
WUE during 2009−10					
N_0	5.0	9.1	11.1	6.5	7.9
N_1	6.8	10.2	11.8	8.7	9.4
N_2	7.7	11.2	11.9	10.0	10.2
N_3	8.6	11.5	12.1	11.1	10.8
Average	7.0	10.5	11.7	9.1	9.6
WUE during 2010−11					
N_0	1.9	3.3	4.1	2.4	2.9
N_1	2.6	3.8	4.5	3.1	3.5
N_2	2.9	4.2	4.6	3.8	3.9
N_3	3.3	4.1	4.7	4.1	4.1
Average	2.7	3.9	4.5	3.4	3.6
3−years pooled	6.6	9.7	10.7	9.3	9.1

under rainfed conditions of the Bundelkhand region. Sesbania−mustard cropping system had also been reported to produce 18.4% higher mustard yield over the fallow−mustard system (Shekhawat *et al.,* 2018). Regar *et al.* (2009) also reported an 18.6% increased seed yield of mustard in sesbania−mustard crop rotation as compared to the fallow−mustard sequence.

Similar to seed yield, WUE was also significantly influenced by different green manure crops and N levels. Averaged over 3 years WUE increased by 41%, 47%, and 62% under green manuring of cluster bean, sunnhemp and sesbania, respectively as compared to the without green manuring (Table 5). The highest WUE was under sesbania green manuring, which may be attributed to the higher seed yield of mustard per unit of water consumed. The WUE progressively increased with increasing N levels and maximum WUE was recorded with 45 kg N ha^{-1}. Sesbania green manure without N application resulted in significantly higher WUE than 45 kg N ha^{-1} without green manuring. The WUE under sunnhemp green manuring was at par with 45 kg N ha^{-1} under control whereas; WUE under cluster bean without N was comparable under control with 30 kg N ha^{-1}. The improved soil properties and higher moisture conservation under green manure−mustard crop rotation enhanced the WUE by 18.8% over the fallow−mustard sequence (Regar *et al.,* 2009). Zhang *et al.* (2016) reported 28% higher WUE in the green manure−wheat system as compared to the fallow− wheat system which may be attributed to improved porosity and water holding capacity of soil due to increased amount of soil organic matter and reduced evapotranspiration over the fallow system (Nielsen *et al.,* 2015).

Economics

The cost of cultivation of the green manure crops was slightly higher than the N levels during all the three years, while the control (no N application) recorded a higher cost of cultivation as compared to plots without green manure crops in all the years (Table 6). The *in−situ* green manuring and different N levels had a significant effect on net return. Sesbania green manuring recorded maximum net return and B:C ratio followed by sunhemp and cluster bean during all the three years. N application at a rate of 45 kg ha^{-1} resulted in a higher net return and B:C ratio, which was at par with 30 kg N ha^{-1}. The three years pooled data also indicates that sesbania green manuring and application of N at a rate of 45 kg ha^{-1} were most profitable over rest of the treatments. About ₹ 3,939/- to ₹ 31,013/- with an average amount of ₹ 14,639/− ha^{-1} (averaged over 6 years) net return had been reported by Singh *et al.* (2019) in sesbania−mustard crop rotation as compared to fallow−mustard crop rotation. Similarly, about 22.4% higher net return has been reported in the sesbania−mustard system (₹ 15570/- ha^{-1}) over fallow−mustard (₹ 12718/-) cropping system. The higher B:C ratio of 2.73 was obtained under the green manuring−mustard system over B:C ratio of 2.59 under the fallow−mustard system (Regar *et al.,* 2009). Green manure−mustard crop rotation had also been reported to increase the net income of farmers by 71.6% as compared to the fallow−mustard sequence in Yamuna ravines (Dubey *et al.,* 2020).

Table: 6
Effect of different green manure crops and N levels on cost of cultivation (₹ ha^{-1}), net return (₹ ha^{-1}) and B:C ratio of mustard

Treatment	2008–09			2009–10			2010–11			3–years pooled		
	Cost of cultivation	Net return	B:C ratio	Cost of cultivation	Net return	B:C ratio	Cost of cultivation	Net return	B:C ratio	Cost of cultivation	Net return	B:C ratio
Green manure crops												
GM_0	8853.8	10269.8	1.16	6771.5	7035.8	1.04	7812.8	7690.3	0.98	7812.7	8332.0	1.06
GM_1	11857.3	17811.6	1.50	9894.3	11379.5	1.15	12022.8	11023.6	0.92	11258.13	13404.9	1.19
GM_2	11857.3	21814.8	1.84	10613.5	13794.1	1.30	12206.8	14461.0	1.18	11559.2	16690.0	1.44
GM_3	12015.8	17767.5	1.48	10037.8	7900.8	0.79	11838.8	8210.6	0.69	11297.47	11293.0	0.99
N Levels												
N_0	10808.5	12592.6	1.17	8986.5	6705.8	0.75	10593.5	6815.0	0.64	10129.5	8704.5	0.85
N_1	11085.5	16456.0	1.48	9284.2	9587.7	1.03	10870.5	9877.3	0.91	10413.4	11973.7	1.14
N_2	11258.0	18616.8	1.65	9436.2	11375.5	1.21	11121.5	11887.9	1.07	10605.23	13960.1	1.31
N_3	11432.0	19998.3	1.75	9610.0	12441.4	1.29	11295.5	12805.4	1.13	10779.17	15081.7	1.39

4. CONCLUSIONS

The *in−situ* green manuring of sunhemp, sesbania and clusterbean was found superior in reducing runoff and soil loss, enriching soil fertility, improving WUE, and increasing crop productivity and profitability over control. Among the various treatments, sesbania was the most efficient *in−situ* green manuring crop with respect to arresting soil erosion and runoff, and enhancing WUE, crop productivity and net income of the fallow−mustard crop sequence. However, the three years pooled data indicated the highest SOC and available N, P, and K content in soil under sunhemp green manuring than rest of the treatments. Moreover, the integration of sesbania green manuring with 45 kg N ha^{-1} was found the most efficient practice in terms of increasing WUE and productivity of mustard over the other treatment combinations. Thus, integration of *in−situ* green manuring with optimum N application is a sustainable approach for improving soil fertility and crop productivity over fallow−mustard crop sequence under rainfed conditions of south−eastern Rajasthan.

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