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Long-term effects of green manuring and herbicides on weeds and productivity of the rice-wheat cropping system in North-Western India

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ABSTRACT

A long-term field experiment from 1999-2000 to 2015-16 at CCS Haryana Agricultural University, Regional Research Station, Karnal, Haryana, India was done to study the effect of green manuring and continuous or rotational use of herbicides on weeds and productivity of the rice-wheat cropping system. Based on data from 2008-09 onward, the density of grassy weeds in the weedy plots under green manuring (GM) (7-37 plants/m^2) remained lower or equal to treatments without green manuring (WGM) (6-37 plants/m^2) in rice with few exceptions. Similarly, broad-leaf weeds (BLW) and sedges under GM (0-83 plants/m^2) remained lower or similar to WGM (0-106 plants/m^2) across different years. In wheat, the density of *Phalaris minor* was higher or similar under GM (55-229 plants/m^2) than WGM (45-177 plants/m^2), while the converse was true for BLW (19-275 plants/m^2 and 45-405 plants/m^2, respectively). The most dominant weed *Echinochloa crus-galli* in rice and *Phalaris minor* in wheat did not develop any envisaged sign of herbicide resistance against continuous and rotational used herbicides in respective crops. Grain yields of rice under weed-free situations were better under GM (6.37-8.30 t/ha) than WGM (5.59-7.63 t/ha). Similarly, the grain yields of wheat were higher under GM (5.25-5.99 t/ha) than WGM (5.08-5.54 t/ha). Consequently, the overall system productivity was better under GM.

INTRODUCTION

Rice in India is grown over an area of about 43 mha with the total production of about 116 m tones, amounting to 41% of the total food grain in the country. Wheat is grown over an area of about 29 mha with total production of about 99 m tones, amounting to 35% of the total food grain production in the country. Rice and wheat crops contribute 76% of the total food grain production in India (Economic Survey 2018-19). It is the most important cropping system covering 10.5 mha area in India and supporting 600 million people. Due to continuous adoption of this monoculture, second generation problems such as declining factor productivity, stagnating crop productivity, declining soil organic matter, receding ground water table, diminishing farm profitability, and environment pollution have begun to appear (Hobbs and Gupta 2000, Sharma *et al.* 2003, Gupta and Sayre 2007, Chauhan *et al.* 2012). Enhanced use and/or abuse of agrochemicals to enhance agriculture production and to manage pests is resulting in reduced soil fertility and productivity and also negatively impacting human health. The use of green manuring is a positive preposition to limit the deleterious effects of agrochemicals.Besides improving the soil health and fertility, it also helps to manage the agricultural pests (Kumar *et al.* 2014). Green manuring has become a common environmentally important agricultural practice for soil quality restoration, maintaining soil organic matter, reclaiming degraded soils, and supplying the plant nutrients (Sinha *et al.* 2009, Kumar 2010). Increased fertilizer costs, pollution, and conservation of energy have further attracted the interest of researchers and low-input farmers in green manuring.Besides improving nutrient availability, green manure improves soil structure and drainage, and stimulates soil microbial growth and activity, with subsequent mineralization of plant nutrients (Eriksen 2005). The availability of N and P utilization is also enhanced due to green manuring.

One of the major benefits of green manuring is its ability to suppress weeds (Blackshaw *et al.* 2001). Green manures cover the ground extensively, which stop the weeds growing beneath them. Green manuring enriches the diversity of a rotation and reduces the opportunities of weeds to become adapted to a particular cropping pattern. *Phalaris minor* Retz. including herbicide resistant populations in wheat and *Echinochloa crus-galli* (L.) P. Beauv. in rice are the two dominant weeds associated with the rice-wheat cropping system (RWCS). In the present situation, intervention in the form of green manuring through *Sesbania aculeata* grown after wheat harvest may be instrumental in improving soil fertility, and avoiding or delaying the development of resistance in *P. minor* against commonly used herbicides (clodinafop, fenoxaprop, and sulfosulfuron). The use of green manures in-between successive crops helps maintain or increase organic matter in soil (Pung *et al.* 2004). *S. aculeata* upon its incorporation in the soil at the succulent stage adds 60-90 kg nitrogen per ha (Pandey *et al.* 2008) and helps to improve the physical and biochemical structure of the soil, prevents leaching losses of nutrients, enhances water holding capacity, prevents weed growth, reduces residual effect of chemicals, and helps in reducing the soil borne inoculum of phyto-pathogens (Kumar 2010). Keeping these points in view, present long-term study was initiated to monitor the long-term impacts of green manuring and continuous or rotational use of herbicides on weed infestation, and sustainability and productivity of the RWCS.

MATERIALS AND METHODS

A long-term field experiment was initiated at CCS Haryana Agricultural University, Regional Research Station, Karnal, Haryana, India during the 1999 rainy season to study the effect of green manuring and continuous or rotational use of herbicides on weed dynamics, sustainability, and productivity of rice and wheat and continued till 2015-16. The soil of the field was deficient in organic carbon (0.35%), sufficient in available phosphorus (12.0 kg P_2O_5/ha), and sufficient in potassium (205 kg/ha) at the beginning of this experiment.

The treatments included continuous (butachlor in rice and clodinafop in wheat) and rotational use of herbicides (pretilachlor, anilofos, and butachlor in rice; and isoproturon, fenoxaprop, pinoxaden, clodinafop, and sulfosulfuron in wheat) along with weedy and weed-free checks in both crops under green manuring (GM) and without green manuring (WGM) (**Table 1**). The treatments were arranged in a randomized complete block design with three replications with a plot size of 23.0 x 6.8 m and all the treatment plots were kept fixed over the years.

The results for this investigation for the years 1999 to 2008 have already been published earlier (Yadav *et al.* 2010a, b, c). Henceforth (from 2008 onwards), the details and results of the same long-term planned experiment have been presented. Due to a heavy buildup of broad-leaved weeds in the wheat crop, blanket sprays of metsulfuron 4 g/ha in winter 2008-09 and 2, 4-D 400 g/ha in winter 2009-10 was done in all plots after recording the weed data in wheat.

Across different years, *Sesbania* as the green manure crop was sown by broadcasting using a seed rate of 25 kg/ha in the month of May in fixed plots assigned to the green manuring treatments. *Sesbania* was incorporated into the soil when it was of knee-high height prior to transplanting of rice followed by ponding of water required for puddling. After puddling, rice was transplanted using 30-45 days old seedlings at a spacing of 20 x 15 cm in the month of July using the cultivar '*HKR-47*' (**Table 1**). Herbicides were applied at 3 days after transplanting (DAT) by broadcasting after mixing in 150 kg sand/ha. In green manured plots, 25% less nitrogen was applied in rice as compared to non-green manured plots. Data on weed density were recorded at 60 DAT, and green yield at harvest. Harvesting of rice was done in the month of October.

After the harvest of rice, wheat was sown in the month of November during different years. Wheat cultivars '*DBW17*', '*DPW621-50*', '*WH711*', and '*HD2967*' were used for sowing in different years of experimentation (**Table 1**). The treatments included fixed herbicide (clodinafop 60 g/ha) and rotational herbicide (isoproturon, fenoxaprop, pinoxaden, clodinafop and sulfosulfuron). Sowing was done at a row spacing of 20 cm using 100-112.5 kg seeds/ha. Herbicides were applied at 35 days after sowing (DAS) using a knapsack sprayer fitted with a flat fan nozzle with a spray volume of 500 L/ha.

Data on weed density were recorded at 75 DAS, and green yield at harvest. Harvesting was done in the second fortnight of April. Both the crops (rice and wheat) were raised according to standard practices of the State Agricultural University.

Before statistical analysis, the data on density of weeds were subjected to square root transformation $(\sqrt{x+1})$ to improve the homogeneity of the variance. The year wise data were subjected to the analysis of variance (ANOVA), and the significant treatment effect was judged with the help of 'F' test at the 5% level of significance (Cochran and Cox 1957). The 'OPSTAT' software of CCS Haryana Agricultural University, Hisar, India, was used for statistical analysis (Sheoran *et al.* 1998).

RESULTS AND DISCUSSION

Effect on weeds in rice

Weed flora of the experimental field during different years in rice mainly included *Echinochloa crus-galli* (L.) P. Beauv. and *E. colona* (L.) Link.; among grasses, *Ammannia baccifera* L. and *Euphorbia microphyla* L. among broad-leaf weeds, and *Fimbristylis miliacea* (L.) Vahl, *Cyperus iria* L., *C. difformis* L., and *C. rotundus* L. among sedges with invariably minor variations over the seasons.

Green manuring resulted in reduced population of grasses, broad-leaf weeds (BLW), and sedges in rice during initial years up to 2008 (Yadav *et al.* 2010a). From 2009 onwards, grassy weeds in weedy check plots under GM (7-37 plants/m^2) remained lower or similar to WGM (6-37 plants/m^2) except in 2013 and 2014 (**Table 2**). Continuous use of butachlor (0-5 plants/m^2) and rotational use of herbicides (0-3 plants/m^2) over the years provided excellent and similar reductions in the population of grassy weeds and were as good as weed-free checks. All herbicidal treatments were superior to the weedy check in reducing grassy weed populations. Similarly, the density of BLW and sedges in weedy check plots was similar or lower under GM than WGM plots up to 2008 (Yadav *et al.* 2010a). Thereafter also the broad-leaf weeds and sedges in weedy check plots under GM (2-83 plants/m^2) remained lower or similar to WGM (23-106 plants/m^2) except in 2012 and 2014 (**Table 2**). No BLW and sedges were present in the field in 2011 and 2015. Herbicides used continuously (0-36 plants/m^2) or in rotation (0-46 plants/m^2) resulted in similar densities of BLW and sedges also. The efficacy of continuous or rotational herbicides at reducing populations of BLW and sedges was generally not influenced by green manuring; however, during 2002, 2008 (Yadav *et al.* 2010a), and 2009 (**Table 2**), efficacy of herbicides was slightly better under green manuring.

The efficiency of continuous or rotational herbicides against weeds was not much influenced by green manuring. There were no signs of development of resistance in weeds against the continuously used herbicide butachlor or rotationally used herbicides over the years since 1999. There were no signs of any adverse effect of continuous use of butachlor on the control of weeds including *Echinochloa crus-galli*, the most dominant weed. The rotational herbicides also performed very well for the control of *Echinochloa*, and were at par with butachlor (fixed herbicide). Similar results on long-term effects of

Table 1. Details of treatments during 2008-09 to 2015-16 in long-term experiment continued since 1999

Particulars	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16
Rice								
Rotational herbicide	-	Pretilachlor	Anilofos	Butachlor	Pretilachlor	Anilofos	Butachlor	Pretilachlor
Variety	-	*HKR 47*	*HKR 47*	*HKR47*	*HKR47*	*HKR 47*	*HKR 47*	*HKR 47*
Date of transplanting	-	25.07.2009	07.07.2010	25.07.2011	15.07.2012	12.07.2013	17.07.2014	07.07.2015
Date of harvesting	-	25.10.2009	22.10.2010	31.10.2011	29.10.2012	25.10.2013	25.10.2014	27.10.2015
Age of seedling (days)		45	35	45	40	40	40	33
Wheat								
Rotational herbicide	Sulfosulfuron	Fenoxaprop	Clodinafop	Sulfosulfuron	Pinoxaden	Clodinafop	Sulfosulfuron	-
Variety	*DBW17*	*DBW17*	*DBW17*	*DPW621-50*	*DPW621-50*	*WH711*	*HD2967*	-
Date of sowing	30.11.2008	22.11.2009	19.11.2010	25.11.2011	20.11.2012	17.11.2013	05.11.2014	-
Date of harvesting	17.04.2009	20.04.2010	23.04.2011	23.04.2012	26.04.2013	24.04.2014	23.04.2015	-
Seed rate (kg/ha)	112.5	112.5	112.5	100	100	112.5	112.5	

Table 2. Long-term effect of continuous or rotational use of herbicides and green manuring on density of weeds in rice during 2009 to 2015 under rice-wheat system in plots maintained since 1999 (*Kharif* 2009 to 2015)

Treatment	Density of grassy weeds in rice (no./m^2)*							Density of broad-leaved weeds and sedges in rice (no./m^2)						
	2009	2010	2011	2012	2013	2014	2015	2009	2010	2011	2012	2013	2014	2015
Green manuring														
Fix herbicide	2.0(3)	1.0(0)	1.0(0)	2.0(3)	1.0(0)	1.0(0)	1.0(0)	3.4(11)	1.0(0)	1.0(0)	3.5(12)	3.6(13)	1.0(0)	1.0(0)
Rotational herbicide	2.2(5)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	4.1(18)	1.0(0)	1.0(0)	1.4(1)	4.3(18)	1.0(0)	1.0(0)
Weed free	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)
Weedy check	4.5(19)	4.6(21)	6.1(37)	4.6(21)	3.1(9)	6.0(35)	2.7(7)	9.2(83)	1.5(2)	1.0(0)	4.4(19)	3.5(12)	4.2(17)	1.0(0)
Without green manuring														
Fix herbicide	1.2(1)	1.0(0)	1.0(0)	1.2(1)	1.0(0)	1.0(0)	1.2(1)	5.8(36)	1.0(0)	1.0(0)	1.5(2)	1.0(0)	1.0(0)	1.0(0)
Rotational herbicide	1.0(0)	1.0(0)	1.0(0)	1.2(1)	1.0(0)	1.0(0)	1.0(0)	6.8(46)	1.0(0)	1.0(0)	2.4(6)	3.2(10)	1.0(0)	1.0(0)
Weed free	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)
Weedy check	4.3(19)	5.6(32)	5.7(32)	6.1(37)	2.6(6)	4.6(21)	2.6(6)	10.3(106)	4.3(23)	1.0(0)	2.6(6)	3.4(12)	3.3(10)	1.0(0)
LSD (p=0.05)	1.28	0.97	0.59	0.93	0.31	0.40	0.4	2.21	1.96	NS	1.55	1.38	0.62	NS

*Original values in parenthesis were subjected to square root transformation $(\sqrt{x+1})$ before analysis green manuring and continuous use of herbicides on weeds have been reported earlier as well (Yadav *et al.* 2010a, c). Lower weed density due to green manuring might be attributed firstly to emergence of weeds during *Sesbania* in the field, which were plowed down before transplanting of rice; and secondly to probability of some allellopathic effects of green manured crop. Reductions in weed infestations in rice due to *Sesbania* green cover crop have been reported by Yadav *et al.* (2011). However, increased weed infestation under green manuring during later years could be probably due to better growing conditions under green manuring both for crop and the weeds. Migliorini *et al.* (2008) did not find any significant effect of green manuring on weeds.

Effect on weeds in wheat

Weed flora of the experimental field mainly included *Phalaris minor* Retz. among grassy weeds, and *Lathyrus aphaca* L., *Coronopus didymus* L., *Vicia sativa* L., *Medicago denticulate* L., *Melilotus indica* L. and *Anagallis arvensis* L. among BLW with obviously some minor variations over the seasons.

The density of grassy weed *Phalaris minor* under weedy check plots was higher under GM at start of the experiment, but lower under GM up to 2005-06 and started increasing later on with similar populations in 2006-07 and higher population under GM in 2007-08 (Yadav *et al.* 2010a). From 2008-09 onwards, the density of *P. minor* in weedy check plots was invariably higher or similar under GM (55-229 plants/m^2) than WGM (45-177 plants/m^2) over the seasons (**Table 3**). Continuous use of clodinafop over the years provided excellent control of *P. minor* in terms of weed density and it was as good as the weed-free check in some seasons. Rotational use of herbicides also provided good control of *P. minor* in terms of weed density (0-50 plants/m^2)*;* however, it was similar or inferior to the continuously applied herbicide clodinafop (0-29 plants/m^2) over the years. All herbicidal treatments were superior to the weedy check in this respect. The efficacy of continuous or rotational herbicides in reducing the density of *P. minor* was generally not influenced by green manuring (1-50 plants/m^2 under GM and 0-41 plants/m^2 under WGM) (**Table 3**), with few exceptions (2001-02, 2003-04 and 2005-06) where weed density was lower under non-green manuring (Yadav *et al.* 2010a).

The population of BLW in weedy check plots under GM was lower than WGM during most of the seasons up to 2007-08 and there was very high buildup of *Lathyrus aphaca* population in non-green manured plots (Yadav *et al.* 2010a). From 2008-09 onwards, the density of BLW under weedy check plots in wheat was invariably lower under GM (19-275/m^2) than WGM (45-405/m^2) (**Table 3**). Similarly, under the fixed herbicidal treatment of clodinafop, which is a grass-killing herbicide, the density of BLW was at par or lower in GM (29-283 plants/m^2) than WGM plots (35-397 plants/m^2). The rotational use of herbicides improved control of BLW (29-189 plants/m^2) than the fixed herbicide (29-283 plants/m^2) treatment under green manuring. The rotational treatment of sulfosulfuron resulted in lowered infestations of BLW in this treatment. The differences between rotational and fix herbicide in respect of density of weeds were very much prominent. The efficacy of sulfosulfuron as rotational herbicides against BLW was invariably better under green manuring.

No signs of development of resistance in *P. minor* were observed against clodinafop used continuously over the years and even with the

Table 3. Long-term effect of continuous or rotational use of herbicides and green manuring on density of weeds in wheat during 2008-09 to 2014-15 under rice-wheat cropping system in plots maintained since 1999 (*Rabi* 2008-09 to 2014-15)

Treatment	Density of grassy weeds in wheat (no./m^2)*							Density of broad-leaved weeds in wheat (no./m^2)						
	08-09	09-10	10-11	11-12	12-13	13-14	14-15	08-09	09-10	10-11	11-12	12-13	13-14	14-15
Green manuring														
Fix herbicide	2.6(6)	2.4(6)	1.4(1)	1.2(1)	4.8(23)	3.0(10)	5.4(29)	10.3(105)	5.4(29)	5.5(29)	16.8(283)	14.1(198)	14.7(216)	15.3(233)
Rotational herbicide	4.8(23)	3.9(15)	2.1(4)	6.4(40)	5.1(25)	2.7(7)	7.1(50)	8.0(63)	6.3(39)	5.4(29)	7.7(59)	11.3(127)	13.8(189)	7.7(60)
Weed free	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)
Weedy check	9.4(88)	10.7(117)	7.5(55)	15.1(229)	14.3(205)	13.4(180)	14.6(213)	9.8(95)	4.4(19)	5.2(26)	16.6(275)	8.2(67)	8.8(78)	13.6(184)
Without green manuring														
Fix herbicide	2.8(9)	1.0(0)	2.9(9)	1.0(0)	3.2(10)	2.4(6)	5.4(29)	14.7(217)	6.0(35)	6.4(41)	19.9(397)	18.1(329)	19.6(385)	17.2(296)
Rotational herbicide	3.6(13)	1.0(0)	1.8(3)	4.8(23)	2.6(6)	2.2(5)	6.4(41)	14.3(205)	6.8(45)	6.8(45)	7.2(52)	14.8(219)	20.1(405)	8.3(70)
Weed free	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)
Weedy check	6.8(45)	7.4(55)	8.3(68)	13.3(177)	10.7(114)	10.1(102)	11.3(139)	14.3(205)	5.8(33)	6.8(46)	19.1(363)	10.8(118)	13.6(184)	15.6(243)
LSD (p=0.05)	1.20	1.81	1.56	1.38	1.80	1.87	1.36	1.66	1.02	0.86	2.38	1.85	1.37	1.87

*Original values in parentheses were subjected to square root transformation $(\sqrt{x+1})$ before analysis.Abbreviations: GM, with green manuring, WGM, without green manuring rotational herbicides. However, there was a slight reduction in the efficacy of the rotational herbicide sulfosulfuron during 2011-12, and 2014-15. Inclusion of pinoxaden as a rotational herbicide in place of fenoxaprop in 2012-13 proved better. The present long-term study indicated that *P. minor* initially decreased but increased with time due to green manuring, but BLW were reduced. BLW were found to increase under non-green manuring particularly in plots treated with fixed herbicides, as no broad-leaved herbicide was used over the years. Consequently, the infestation of BLW particularly *Lathyrus aphaca* under non-green manured plots became very serious in 2007-08, for which BLW herbicide was used across all the treatments to scale down its infestation. The higher density of *P. minor* under GM as compared to WGM could be due to improvement in soil conditions under GM with time, which proved favorable for *P. minor* as well, hence the weed started building up after some time. Long-term effects of green manuring in reduction of weed infestation initially in wheat and build up later on have been reported earlier as well (Yadav *et al.* 2010a, c). However, Migliorini *et al.* (2008) did not find any significant effect of green manuring on weeds.

Effect on rice crop productivity

Continuous or rotational use of herbicides provided statistically similar grain yield of rice (5.28-7.45 t/ha) which was better than weedy check plots (3.19-5.53 t/ha) both under GM and WGM (**Table 4**). The grain yield was highest under the weed free treatment (5.59-8.30 t/ha), which was similar or higher to the herbicidal treatments across different years. The grain yield under green manuring (3.66-8.30 t/ha) was higher than non-green manuring (3.19-7.63 t/ha) under different treatments over the years with few exceptions; however, the differences were not always significant. The grain yield of rice under weed free situations was better under GM (6.37-8.30 t/ha) than WGM (5.59-7.63 t/ha) over the years.

Effect on wheat crop productivity

The grain yield of wheat was higher under green manuring over the years; however, the differences were not significant with few exceptions (**Table 4**). The continuous or rotational use of herbicides provided statistically similar grain yield of wheat (4.52-5.80 t/ha), which was better than weedy check plots (1.65-3.86 t/ha) both under GM and WGM. The grain yield was highest under the weed free treatment (5.08-5.87 t/ha), which was similar or higher to the herbicidal treatments across different years. Grain yield of wheat in herbicide treated or weed free treatments under green manuring (4.75-5.99 t/ha) was higher than non-green manuring (4.52-5.58 t/ha) under different treatments over the years with few exceptions; however, the differences were not always significant.

The system productivity of the RWCS was higher under green manuring than non-green manuring. Increases in the yield of rice and measurable effects on the succeeding crop of wheat due to green manuring have been reported earlier also (Mann *et al.* 1994, Yadav *et al.* 2010a, b, c).

Green manuring reduced the population of grasses, BLW, and sedges in rice, however, with time weeds started building up in GM as well. In wheat, infestation of *Phalaris minor* was lower under green manuring initially, but increased with time and

Table 4. Long-term effect of continuous or rotational use of herbicides and green manuring on grain yield of rice (2009 to 2015) and wheat (2008-09 to 2014-15) under rice-wheat cropping system in plots maintained since 1999

Treatment	Grain yield of rice (t/ha)							Grain yield of wheat (t/ha)						
	2009	2010	2011	2012	2013	2014	2015	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15
With green manuring														
Fix herbicide	7.22	7.07	5.74	6.77	6.71	7.45	7.38	5.17	4.85	5.80	5.36	5.43	5.41	5.68
Rotational herbicide	6.94	6.85	5.61	6.66	6.65	7.41	7.47	5.09	4.75	5.60	5.31	5.44	5.17	5.69
Weed free	7.57	7.31	6.37	7.05	6.63	7.90	8.30	5.54	5.25	5.99	5.63	5.59	5.64	5.87
Weedy check	4.41	3.66	3.73	4.64	4.87	4.51	5.53	3.34	1.65	3.22	3.86	3.69	3.54	3.32
Without green manuring														
Fix herbicide	6.22	6.52	5.30	6.32	5.67	6.95	7.11	4.89	4.60	5.55	5.19	5.13	4.80	5.38
Rotational herbicide	5.97	6.35	5.28	6.23	5.65	7.14	7.14	4.71	4.52	5.47	5.14	5.14	5.18	5.40
Weed free	6.65	6.74	5.79	6.61	5.59	7.43	7.63	5.27	5.08	5.52	5.39	5.49	5.58	5.54
Weedy check	4.03	3.19	4.11	4.20	4.04	5.14	4.03	3.43	2.81	3.20	3.89	3.20	3.83	3.26
LSD (p=0.05)	0.69	0.46	0.66	0.42	0.45	0.25	0.20	0.33	0.38	0.31	0.27	0.32	0.41	0.29

became higher than non-green manuring. The BLW in wheat were invariably lower under GM. There were no signs of development of resistance in weeds including *Echinochloa crus-galli* against continuously (butachlor) or rotationally used herbicides (butachlor, pretilachlor, and anilofos) in rice, and *Phalaris minor* against continuously (clodinafop) or rotationally used herbicides (clodinafop, fenoxaprop, sulfosulfuron and pinoxaden) in wheat. Productivity of rice and wheat crops and RWCS as a whole were better under GM over the years. However, the impact on rice yield was more pronounced. This study established the importance of *Sesbania* green manuring in RWCS on long-term basis.

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