Review Paper

Effect of brown manuring on soil properties, weed density, grain yield and economics of different crops

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ABSTRACT

Brown manuring in conjunction with pre-emergence herbicide(s) significantly improves the soil physico-chemical properties viz., organic matter, soil aggregation, available nitrogen, concentration of available nutrients in the root zone and reduces the bulk density, N-losses through leaching and soil erosion. Vegetative cover prevents the build-up of aggregates which could lead to the formation of surface crust which in turn increases soil infiltration rate. Integration of herbicide(s) with brown manuring markedly improved protein content in grain and protein yield than other management practices. Grain yield of direct seeded rice with *Sesbania* brown manuring was statistically at par with conventional transplanting of rice. Brown manuring can replace 25 per cent of nitrogenous fertilizer with the overall improvement of soil health. It aimed at suppressing the weeds by its competitive nature and shade effect with improvement in the soil physico-chemical and biological properties.

Keywords: Brown manuring, herbicide, soil organic carbon, weed control

1. INTRODUCTION

The rising cost of cultivation and less availability of inputs is the present scenario of agriculture. In India, now re-defining the farming practices and increased attention is paid towards the development of resource conservation practices. There are many options available, among them ‘brown manuring’ is becoming a recent trend developed for paddy eco-system and is also becoming a popular technique in agriculture. Traditionally, farmers grow green manure crops before rice culture and incorporate it by puddling before transplanting rice seedlings and this requires more number of tillage operations for green manuring leads to loss of soil moisture and also it needs additional irrigation water and fuel costs for incorporation. Since there is water scarcity during peak summer, farmers have not been able to take full advantage of green manuring in rice growing season. So, Brown manuring is the alternative practice to the green manuring. It can be defined as a technique of growing green manuring crops viz*.,* dhaincha, *sesbania*, sunnhemp *etc*., as an inter or mixed crop and killing them by the application of post-emergence herbicides for manuring. After spraying, the colour of green crops becomes brown due to loss of chlorophyll, hence the process is called as brown manuring [1]. Brown manuring practice was introduced where *Sesbania* crop @ 20/25 kg ha^{-1} was broadcasted three days after rice sowing and allowed to grow for 30 days. Co-cultured *Sesbania* crop was dried by spraying 2,4-D ethyle ester [2, 3]. The dried leaves of *Sesbania* fell on the soil and decomposed very fast to supply nitrogen, dry matter, soil organic carbon and other recycled nutrients to the soil. The practice led to reduction of weed population by nearly half without any adverse effect on rice yield. Pest attack was also reduced [4, 5, 6]. Brown manuring can be practiced in maize, rice, sugarcane *etc*. It is an advanced weed management strategy as well as no till version of green manuring using a non-selective herbicide. It aims at suppressing the weeds by shading. Like green manuring, brown manuring also impacts positively on soil organic matter, improving the soil physico-chemical properties and its associated microbes. It also act as a surface mulch, conserves soil moisture, supplies 10-15 kg of N ha^{-1} on decomposition and also facilitates emergence of crop seedling in soils having problem of crusting in the succeeding crop and provides inoculums for the microbes active on the surface-retained residues that help in degradation of the residues, offset the green house gas emission and increases the productivity [7]. This may also be a preferred option on lighter soils prone to erosion and reduce weeds [8, 9]. Due to its advantages, it helped farmers to shift from puddle transplanted rice to direct seeded aerobic rice.

1.1 CROPS SUITABLE FOR BROWN MANURING

Non leguminous crops: The non leguminous crops used as a green manuring crop which provide only organic matter to the soil. The non legumes are used for green manuring to a limited extent.

Example : Niger, Wild indigo *etc.*

Leguminous crops: Crops provide nitrogen as well as organic matter to the soils. Legumes have the ability of acquiring nitrogen from the air with the help of its nodule bacteria. The legumes are preferably used in green manuring crops

Example : Sunnhemp, Dhaincha, Mung, Cowpea, Lentil *etc.*

Table 1. Nutrient content and C : N ratio of major green manure crops

Green manure crop	Total N (%)	C:N ratio	Total P (%)	Total K (%)
Sunnhemp (*Crotolaria juncea*)	3.97	21:1	0.37	4.80
Dhaincha (*Sesbania aculeata)*	1.90	44:1	0.34	3.60
Sesbania (*Sesbania speciosa)*	2.71	40:1	0.53	2.21

Source [10]

2. EFFECTS OF BROWN MANURING ON PHYSICO-CHEMICAL PROPERTIES OF SOIL

Brown manuring has its positive impact on soil physico-chemical properties viz., soil structure, organic carbon, bulk density and pH of the soil. Zero tillage with *Sesbania* as brown manuring in rice significantly increases Organic carbon (0.55 %), hydraulic conductivity and decreases the bulk density. This was due to rice, wheat residue and brown manuring effect of *sesbania* on soil properties. Sesbenia seed sown @ 25 kg ha^{-1} and after 35 days sowing, foliar application of 2,4-D (sodium salt) @ 625 g in 500 liter of water sprayed on the crop [11].

The results revealed that, productivity of sugarcane increased from 67.9 to 76.2 t ha^{-1}, increased soil organic matter (organic carbon) from 0.30 to 0.75 per cent and decreased the pH from 8.0 to 7.2 [12]. The soil organic carbon was increased by 0.03-0.05 per cent due to brown manuring. More response was found in sodic soil [13]. Organic carbon builds up was higher in inclusion of brown manure (0.52 ± 0.04 %) and 13.04 per cent more carbon build up was recorded when compared to farmers practice (0.46 ± 0.04 %). The increased organic carbon content might be attributed to the addition of organic materials from brown manuring and better root growth of the crops grown [14]. The highest concentrations of total N, soil organic carbon, porosity, soil organic matter, soil microbial biomass carbon, and soil microbial biomass nitrogen were recorded with direct seeded aerobic rice + *sesbania* brown manuring-no tilled wheat and also lowest soil bulk density and total soil porosity at 0-5 cm depth were recorded with the same treatment [15]. Indeed, *sesbania* is a fast-growing and high biomass producing legume crop, which can fix a large amount of atmospheric nitrogen into plant usable form [16, 17].

Table 2. Effect of brown manuring on soil organic carbon and post harvest available nitrogen

Year	Initial organic carbon content of soil (%)	Organic carbon content after harvest (%)	% increase in organic carbon	Initial soil available nitrogen content (kg/ha)	Soil available nitrogen content after harvest (kg/ha)	% increase in soil available nitrogen
2014	0.54	0.69	0.15	283.0	320.2	13.1

2015	0.58	0.71	0.13	285.38	324.6	13.7
Mean	0.56	0.70	0.14	284.19	322.4	13.4

*IP: Improved technology (Brown manuring) FP: Farmer's practice (Indiscriminate use of chemical fertilisers)

Source: [53]

3. EFFECTS OF BROWN MANURING ON SOIL MOISTURE

The brown manuring practice improves the soil physical properties results in higher moisture holding capacity, hydraulic conductivity and decreases the moisture evaporation from the soil. Pre-emergence application of Alachlor @ 1 kg ha^{-1} + Brown manuring (dhaincha) recorded highest available soil moisture followed by pre-emergence application of Alachlor @ 1.0 kg ha^{-1} + diancha as intercrop with in-situ incorporation on 35 DAS [18]. This was due to ability of dhaincha to impove the moisture holding capacity of the soil. The maximum water saving can be done in the direct seeded rice with Sesnania co-culture as brown manuring (39.4 %) followed by direct seeded rice compared to transplanted rice. However, the gross water productivity was maximum (0.31 kg m^{-3}) where, rice cultivation was done through direct seed sowing with *Sesbania* (Brown manuring) [19]. The residue retained plot under zero till rice and wheat followed by *Sesbania* brown manuring resulted in more soil moisture content during both the years of study at 0-15 cm and 15-30 cm soil depth and lower was recorded under direct seeded rice followed by conventional wheat with incorporation of *Sesbania* [20]. It might be due to reduced water evaporation [21, 22]. Water use efficiency (WUE) of maize significantly increased with mulching over no mulching. Water use efficiency was significantly high with wheat straw mulching treatment (20.13 kg ha^{-1} mm) and was at par with sunhemp brown manuring (two rows) (19.67 kg ha^{-1} mm) [23].

4. EFFECTS OF BROWN MANURING ON WEED DENSITY

No doubt herbicides are important tools to control weeds. But because of concerns about the evolution of herbicide resistance in weeds, shift in weed population, and less availability of new and broad-spectrum herbicides, there is a need to integrate herbicide use with other measures like brown manuring to control weeds. In recent years, more attention has been given to the possibilities of exploiting brown manuring to aid in weed management. It aimed at suppressing the weeds without affecting the soil physico-chemical properties and its associated microbes. It can be achieved through raising green manure crops such as *Sesbania* (Daincha), sunhemp *etc*. as inter crop and killing the same by application of post-emergence herbicides. The killed manure is allowed to remain in the field along with main crop without incorporation / in-situ ploughing until its residue decomposes itself in the soil aiming to add organic manure beside weed suppression by its shade effect. A lower broad-leaved weed density and dry weight were observed with *Sesbania* and other brown manuring species than the surface mulch. Brown manuring helps in smothering weeds and conserving moisture without adding much on cost of production [24]. To use brown manuring for weed control, pulse crops must be desiccated at or before the milky dough stage of the target weeds. This is usually at or before the flat pod stage of the pulse, well before the crop's peak dry matter production. At this stage, the crop is growing at its maximum rate about 80 to 100 kg of dry matter per hectare per day.

Sesbania co-culture technology can reduce the weed population by nearly half without any adverse effect on rice yield [25]. It involves seeding of rice and *sesbania* crops together and then killing *Sesbania* with 2, 4-D ester about 25-30 DAS. *Sesbania* grows rapidly and suppresses weed flora. This practice is found more effective in suppressing broadleaf weeds than grasses and therefore if combined with pre-emergence application of pendimethalin, its performance in suppressing weeds increases. The weed management practice of PE alachlor 1.0 kg ha^{-1} + brown manuring proved to be effective in registering the lowest weed density of grasses, sedges, broad-leaved weeds and total weeds at 20, 40 and 60 DAS and was at par with PE alachclor 1.0 kg ha^{-1} + daincha as intercrop with in-situ incorporation on 35 DAS except at 20 and 40 DAS. The above said prominent treatment has also registered higher weed control efficiency (84.41, 92.15 and 89.65 % at 20, 40 and 60 DAS, respectively) [18]. Integration of pendimethalin with either brown manuring or bispyribac and brown manuring had markedly lower dry weight of all weed species thus recorded higher weed control efficiency than other weed management practices. A lower broad-leaved weed density and dry weight were observed with *Sesbania* and other brown manuring species than the surface mulch. Intercropping of brown manuring crops with rice reduced weed densities by about 40- 50 per cent [26]. Application of wheat residue mulch at 4 t ha^{-1} and *Sesbania* intercropping for 30 days were equally effective in controlling weeds in dry-seeded rice [2]. A greater reduction in weed density was recorded when *Sesbania* and rice seeding were done simultaneously than when sowing *Sesbania* at 5 days after rice seeding. Butachlor + brown manuring + 2, 4- D was able to reduce weed pressure, as brown manuring acted as a cover crop in suppressing weed growth effectively [27, 28]. Rice + *Sesbania* (Brown manuring (BM) of *Sesbania* at 4 WAS) and rice + *Sesbania* (Brown manuring (BM) of *Sesbania* at 5 WAS) reduced early weed density and dry matter in direct seeded rice [24].

In another study, *Sesbania* co-culture reduced broadleaf and grass weed density by 76–83 per cent and 20–33 per cent, respectively, and total weed biomass by 37–80 per cent compared to sole rice crop. Intercropping of brown manuring crops with rice reduced weed densities by about 40-50 per cent [29]. The facultative weed *Eupatorium* has been reported a good source of organic matter and weed suppressor for several upland crops including direct seeded rice in Himachal Pradesh [30]. Among the weed control treatments, broadcasting of *Sesbania* knocked down by the application of 2,4-D 0.5 kg ha^{-1} at 30 DAS recorded the lowest weed density [31]. Application of pendimethalin *fb* brown manuring had statistically lowest dry weight of grasses and highest grass control efficiency among all weed management practices. However, significantly lowest values of sedges and BLW dry matter were registered under application of pendimethalin *fb* bispyribac *fb* brown manuring, and consequently leading to highest control efficiency of sedges and BLW [32]. Pendimethalin and bispyribac were reported to be effective against most of grassy weeds [33, 34].

Results obtained from the experiment revealed that, among the herbicides + cultural methods of weed control, combination of butachlor + brown manuring + 2,4-D application at 40 DAS recorded lowest weed dry weight at 60 DAS leading to highest value of weed control efficiency of 86.0 per cent in 2006 and 88.15 per cent in 2007. The lowest weed index value (4.5 and 2.5 % in 2006 and 2007, respectively) recorded by the same treatment. Highest value of weed control efficiency and lowest value of weed index of butachlor + brown manuring + 2,4-D reflected its selectivity and higher efficacy in controlling weeds. Butachlor + brown manuring + 2,4-D was able to reduce weed pressure as brown manuring acted as a cover crop in suppressing weed growth effectively at the initial growth stage [35]. The similar results were also reported by [36, 37, 38]. Drum seeding alone or drum seeding + dhaincha brown manure [39] or growing of one row of *Sesbania rostrata* between two paired rows of rice [40] was found effective in reducing density and dry matter accumulation of weeds. Sunnhemp brown manuring (two rows) recorded significantly lower weed dry weight (4.03 g m^{-2}) followed by wheat straw mulching. Weed control efficiency (77.97 %) was higher in sunnhemp brown manuring treatment and was followed by wheat straw mulching (74.60 %) [23]. This might be due to the suppression of weeds by the shade effect of sunnhemp crop residue. They also revealed that maximum weed density was observed in sole crop of rice (68 weeds m^{-2}) as compared to only (15 weeds m^{-2}) in *Sesbania* sown along with rice. Direct seeding with *Sesbania* co-culture as a brown manuring yielded (4.51 t ha^{-1}) at par with conventional transplanting (4.70 t ha^{-1}) and significantly higher than direct seeding without brown manuring (4.00 t ha^{-1}) [41]. Maximum weed density was observed in direct seeding without brown manuring (40 weeds m^{-2}) whereas, direct seeding with brown manuring (15 weeds m^{-2}) and conventional transplanting (16 weeds m^{-2}) gave at par weed density [42]. The best time for incorporating *sesbania* for maximum weed suppression and grain yield was at 30 DAS for semi-dry rice and the best method for knocking down *sesbania* was 2, 4-D spraying @ 1 kg ha^{-1}. *Sesbania* brown manuring in direct-seeded aerobic rice (DSAR) reduced the density of broad-leaved weeds, narrow-leaved weeds, and sedges by 56 per cent, 41 per cent, and 50 per cent, respectively, than the sole crop of DSAR. Likewise, dry weight of the broad-leaved weeds, narrow leaved weeds, and sedges was reduced by 75 per cent, 65 per cent, and 62 per cent, respectively, than in the sole crop of DSAR [43]. It is because of decreased availability of sunlight to the germinating weed seeds and weed plants, which inhibited the weed seed germination and photosynthesis [44, 45]. Study conducted by ICAR [46] revealed that growing cowpea or daincha as an intercrop and pre-emergence application of pendimethalin @ 1 kg ha^{-1} followed by hand weeding at 20 DAS as an integrated strategy has been found appropriate for reducing the weed competition in upland direct seeded rice.

Table 3. Effect of brown manuring on weed density in maize

Treatment	Weed density/ m^2	WCE (%)
Mechanical weeding by hand hoe at 20 and 35 DAS	19.82	80.50
Alachlor@ 1.0 kg ha^{-1}as PE + Mechanical weeding at 35 DAS	18.48	81.50
Dhaincha as intercrop with in-situ incorporation at 35 DAS	25.66	74..80
Brown manuring (2,4-D @ 0.5 kg ha^{-1}at 35 DAS)	24.15	75.80
Alachlor@ 1.0 kg ha^{-1}as PE + Dhaincha as intercrop with in-situ incorporation at 35 DAS	14.19	86.00
Alachlor@ 1.0 kg ha^{-1}as PE + Brown manuring	10.52	89.70
Unweeded check	101.65	---
CD (P = 0.05)	0.054	---

Source: [18] *WCE: Weed control efficiency

Rice + *Sesbania* (Brown manuring at 4 WAS) (pendimethalin @ 750 g ha^{-1} followed by post-emergence bispyribac @ 25 g ha^{-1})

Source: [24]

Rice + *Sesbania* before spray **Rice + *Sesbania* after spray**

Source: [24]

5. EFFECTS OF BROWN MANURING ON NUTRIENT USE EFFICIENCY

As there is a rising trend in the chemical fertilizer cost, brown manuring would form an alternative approach for higher production and net benefit. By the practice brown manuring can replace 25 per cent of nitrogenous fertilizer with the overall soil health [14]. *Sesbania* crops were knocked down by herbicide after 30 days when it is tender and succulent so as to get maximum response and makes N available immediately after application. Nutrient use efficiency (NUE) was positively influenced by weed management practices. Among the integrated weed management practices, nutrient use efficiency of N (50.00 and 64.67 kg grain yield kg^{-1} nutrient applied), P (229.36 and 296.64 kg grain yield kg^{-1} nutrient applied) and K (90.36 and 116.87 kg grain yield kg^{-1} nutrient applied) was highest under butachlor 1.5 kg ha^{-1} + brown manuring + 2,4-D 0.5 kg ha^{-1} treated plots during both the years of investigation [35]. Growing of direct seeded rice + brown manuring increased the available nitrogen (102 kg ha^{-1}), available phosphorus (22.1 kg ha^{-1}), available potassium (265.9 kg ha^{-1}) in soil compared to transplanted rice [11].

Table 4. Effect of replacing 25 per cent nitrogenous fertilizer by brown manuring on economic indicators

Parameters	Farmer's practice	Brown manuring	Per cent increase
Grain yield (q ha^{-1})	45.5±2.98	49.1±2.21	7.91
Organic carbon (%)	0.46±0.04	0.52±0.04	13.04
Benefit to cost ratio	1.54±0.26	1.66±0.19	7.79

Source: [14]

6. EFFECTS OF BROWN MANURING ON GROWTH AND YIELD OF CROPS

Integration of herbicide/herbicides with brown manuring markedly improved protein content in grain and protein yield than other management practices [32]. *Sesbania* intercropping resulted increased grain yield and net income of direct seeded rice (DSR) by 15 per cent compared with the plots where no intercropping was done [2]. The greatest DSR yield with mixed cropping of rice and *Sesbania aculeata*

[36]. Paddy yield in bed transplanting (4.43 t ha^{-1}) and direct seeding + brown manuring (4.23 t ha^{-1}) were at par and significantly higher than direct seeding without brown manuring (3.36 t ha^{-1}) that produced the lower yield [47]. Direct seeding with *Sesbania* co-culture as a brown manuring yielded (3.65 t ha^{-1}) at par, compared to conventional transplanting (3.69 t ha^{-1}) and significantly higher than direct seeding without brown manuring (3.24 t ha^{-1}) [48]. Direct seeding with *Sesbania* co-culture as a brown manuring yielded (4.51 t ha^{-1}) at par with conventional transplanting (4.70 t ha^{-1}) and significantly higher than direct seeding without brown manuring (4.00 t ha^{-1}) [7]. Rice yield in direct seeding + brown manuring (3.50 t ha^{-1}) were at par compared to conventional transplanting (3.56 t ha^{-1}) but significantly higher than direct seeding without brown manuring (3.22 t ha^{-1}) [11]. Pre-emergence application of butachlor @ 1.5 kg ha^{-1} as pre-plant surface application + brown manuring with *Sesbania rostrata* + 2,4-D @ 0.50 kg ha^{-1} recorded the highest grain yield (3.88 t ha^{-1}), which was at par with that obtained from season-long weed-free situation (3.98 t ha^{-1}) [27].
The treatment combination of rice + BM (4 WAS) with pendimethalin 750 g ha^{-1} *fb* bispyribac 25 g ha^{-1} recorded the highest grain yield (59.68 q ha^{-1}) which was significantly higher than all other combinations of brown manuring with herbicide treatments [26]. Pendimethalin @ 1.0 kg ha^{-1} has been quite effective and economical in DSR for reducing weed count and their biomass and increasing grain yield whether applied as a sole treatment or followed in sequence with a post-emergence herbicide [49]. The higher grain yield was obtained from brown manuring + inorganic fertilizer treatment and it was identical to soil test based inorganic fertilizer for high yielding genotype (HYG). The highest gross margin was also obtained from brown manuring + inorganic fertilizer treatment [50]. Pre-emergence application of pendimethalin *fb* brown manuring and pendimethalin *fb* bispyribac *fb* brown manuring resulted in significantly higher grain yield than other weed management practices. This result could be attributed to higher weed control efficiency and increased crop growth under these treatments [51]. Pre-emergence application of pendimethalin @ 1.0 kg ha^{-1} + Brown manuring at 30 DAS + Hand weeding at 60 DAS recorded the highest dry matter production and grain yield (4.12 t ha^{-1}) which were statistically at par to all other weed management practices except weedy check. Brown manuring of dhaincha suppressed the weeds and increased the availability of nutrient [52]. *Sesbania* sown at 4 days of rice seeding recorded maximum yield (5.54 t ha^{-1}) and it was at par with *Sesbania* sown at 5 days of rice seeding (5.41 t ha^{-1}) and significantly higher than sole crop of rice (4.70 t ha^{-1}) [41]. The brown manuring practice recorded 16.15 per cent higher grain yield (30.2 q ha^{-1}), higher harvest index (47.34 %), production efficiency (28.8 kg ha^{-1} day^{-1}) and extension gap (4.2 q ha^{-1}) than farmer's practice [53].

Table 5. Effect of brown manuring on available nutrient status and sugarcane yield

Village	Available N (kg ha^{-1})		Available P (kg ha^{-1})		Available K (kg ha^{-1})		Sugarcane production (MT ha^{-1})	
	BBM	ABM	BBM	ABM	BBM	ABM	BBM	ABM
Ladwa	244	335	85	132	13.6	15.9	68.1	76.0
Kajikhera	238	339	97	142	14.8	16.9	68.2	76.3
Mukundpur	262	333	92	127	16.0	18.20	67.5	76.4

*BBM – Before brown manuring, ABM - After brown manuring MT- Mega tonnes
Source : [12]

7. EFFECTS OF BROWN MANURING ON ECONOMICS OF DIFFERENT CROPS

Pre-emergence application of butachlor @ 1.5 kg ha^{-1} + brown manuring + 2, 4-D 0.5 kg ha^{-1} registered highest net return (Rs.19,029 ha^{-1}) as well as benefit cost ratio (1.19) during both the years. This might be owing to high weed control efficiency with least man day's engagement and higher grain yield [35]. Maximum productivity of grain and stover yield with PE alahclor @ 1.0 kg ha^{-1} + brown manuring had resulted in the highest net return of Rs. 45,993 $ha^{-1}$and benefit cost ratio of 3.061 [18]. This might be due to higher economic yield recorded in this treatment. This result was in conformity with the findings of [54]. Cost and return analysis showed that the highest gross returns (Tk 2,62,335 ha^{-1}) and gross margin (Tk. 1,47,028 ha^{-1}) was obtained from brown manuring + inorganic fertilizer. Butachlor @ 1.5 kg ha^{-1} as pre-plant surface application + brown manuring with *Sesbania rostrata* + 2,4-D @ 0.50 kg ha^{-1} recorded The highest net returns (Rs 19,029 ha^{-1}) and benefit cost ratio (1.19) [27]. The treatment combination of rice + BM (4 WAS) and pendimethalin *fb* bispyribac recorded the highest net return (66,356 ha^{-1}) and B:C was 3.36 [24]. *Eupatorium* mulch recorded higher gross returns of Rs. 1,01,800 ha^{-1} compared to rest of the treatments and was par with brown manuring with *Sesbania* (Rs. 93,670 ha^{-1}) and BC ratio of *Eupatorium* mulch was 2.4 and BM with *Sesbania* was 2.3 [26]. Brown manuring practice recorded the higher gross return of Rs.45,146 ha^{-1}, higher BC ratio (1.47) and profitability (Rs. 143.66 ha^{-1} day^{-1}) with additional net return of Rs.5,271 ha^{-1} over farmers practice [53].

8. CONCLUSION

Brown manuring is a practices where plant material is returned to the soil to improve soil fertility, available nutrients, soil porosity, cation exchange capacity (CEC), aggregation of soil particles and helps to reduce bulk density of soil. It also conserves the soil water, reduces the weed and disease burdens and has potential to increase soil organic carbon. This would help to offset greenhouse gas emissions. Weed suppression and improvement of soil properties with *sesbania* brown manuring in turn leads to enhanced productivity and profitability of the crops. Weeds in DSR can be effectively controlled by application of pendimethalin 1 kg ha^{-1} followed by brown manuring of dhaincha at 25 DAS by 2,4-D @ 0.50 kg ha^{-1}. Direct seeded rice + *Sesbania* as brown manuring is the best option for highest yield of rice with higher water productivity. It will give comparable yield of rice and higher economic returns to conventional transplanting.

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