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Brown Manuring-An Eco-friendly Approach towards Sustainability in Agriculture: A Review

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ABSTRACT

Agriculture sustainability depends on production of crops without hampering natural systems and thus, suggests for eco-friendly approaches to achieve this. Weed, being a major problem in agriculture causes reduction in crop yield and depletes soil nutrients. Although application of inorganic fertilizers or herbicides improves crop yield to an extent, it hampers soil health and environment through toxic substances. In this context, brown manuring, an organic/eco-friendly approach holds good prospect, specially in direct seeded rice. Reviewed research reports clearly explained the benefits of brown manuring in suppression of weeds, sequestration of carbon, biological nitrogen fixation, addition of macro and micro nutrients to soil, saving soil moisture, improving physical, chemical and biological properties of soil *etc*. As a consequence, various research works reported improvement in crop growth, yield and economic return of rice, maize, sugarcane *etc*. However, research gap is still present in this regard and therefore, multi-locational, multi-season, multi-crop trials using different brown manure plants at different rates and time of co-culture are needed at this hour to confirm the efficacy of brown manuring for future recommendation. Besides, strong extension service is needed further to transfuse this eco-friendly approach to grass-root level of farming community.

Key words: Agriculture sustainability, Brown manuring, Eco-friendly approach, Soil health, Weed, Yield.

Consistent rise in human population urges for elevation in crop productivity to ensure food security. To achieve this, specially, in contexts of agricultural land shrinkage and climate change, farmers are opting intensive cropping approach which not only depletes soil fertility but also creates pest resurgence. Application of inorganic fertilizer or chemical pesticides is now a regular phenomenon in intensive agriculture. Although inorganic fertilizer improves the crop productivity, in a long run, it cannot be advised as it creates deficiencies of many secondary and micro nutrients in soil and damages soil physical, chemical and biological properties (Kumar *et al*., 2014). Already, stagnation in agricultural production with use of large quantity of fertilizers has been reported in many places (John and Babu, 2021). Consistent application of chemical pesticides season after season, on another side, is creating pest resistance. Both these chemical fertilizer and pesticides persist in soil for long time and thus, leave toxic footprints in environment (Nayak *et al*., 2020; Biswas and Dutta, 2019; Neog, 2018). Further, excessive application of these inorganic materials add additional cost of cultivation of crops. Therefore, an organic/eco-friendly option either solely or in combination with above inorganic materials is most needed to elevate agricultural productivity in a sustainable manner along with environment safety to an extent. In this context, one eco-friendly approach called 'brown manuring' can find suitable place towards achieving sustainability in agriculture. It not only serves as an effective weed management option but also improves soil quality by adding both macro and micro nutrients and accelerating biological activities. As a consequence, it increases the crop productivity and ensures reduction of environmental hazards to an extent. It helps in achieving high nutrient and water use efficiencies of crops like rice and saves carrying cost of bulky organic manure(s).

Rice is mostly grown as transplanted crop which requires high quantity of water along with various intercultural operations for land preparation, puddling, nursery raising, transplanting *etc*. and thus, increases cost of cultivation (Maity and Mukherjee, 2009). Therefore, direct seeding of pre-germinated rice seeds can be a suitable alternative of transplanting if weeds are controlled properly (Raj and Syriac, 2017). Weed infestation in direct seeded rice (DSR) can cause around 45-90% yield reduction (Singh, 2014). Success of DSR depends on effective weed management strategy as well as better soil health and both these can be achieved through brown manuring (Iliger *et al*., 2017). Research reports explore that brown manuring holds good prospect not only in rice ecosystem but also in many other crops. With this backdrop, a review has been made

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elucidating the role of brown manuring as an eco-friendly approach of weed and nutrient managements to achieve sustainability in production of rice and other crops.

Brown manuring

Brown manuring is the zero tilled version of green manuring, which is practiced before flowering as one of the carbon farming approaches, particularly in loamy to clay soil to sequester carbon into the soil. This practice is mostly seen in DSR under the cases of both line sowing and broadcasting and usually not done in transplanted rice. However, it has been also reported to be practiced in other crops like maize, sugarcane *etc*. Rice and brown manure plants (*viz*. sesbania, sun hemp *etc*.) are grown together and when sesbania/sun hemp plants reach greater heights than rice after 25-30 days of co-culture, they are killed by spraying a selective post emergence (POE) herbicide like 2, 4-D ethyl ester @ 500 g/ ha. 4-5 days after spraying, as sesbania/sun hemp plants turn brown colour due to knock down effect of the herbicide and die, they are called brown manure plants (Tanwar *et al*., 2010). The dead plants are kept standing in the field without incorporating into the soil, allowing the residues of brown manure plants to fall and cover the soil surface as well as to decompose and add nutrients and organic carbon into the soil. Brown manuring was first practiced in N-S Wales, Australia's Lock Hart district in 1996 (Patil *et al*., 2020). In Australia, it was used in winter crops against herbicide resistant rye grass. Brown manuring is a suitable alternative of green manuring as later one requires labour, fuel, irrigation water (constraint specially, in rice during summer season) and time for plant's incorporation into the soil as well as certain temperature and sufficient soil moisture for its decomposition, which may not always be feasible throughout the year and in all location.

Suitable plants for brown manuring

Both non-leguminous and leguminous plants can be used for brown manuring. Non-legumes add organic matter only, while legumes add organic matter and undergoes biological nitrogen fixation (BNF). Some notable non-leguminous plants such as niger, wild indigo *etc*. and leguminous plants such as sun hemp, sesbania (*dhaincha*), mung, cowpea, lentil, *kharif* pulses *etc*. are used for brown manuring. For efficient brown manure production, careful selection of suitable plant is very important. Brown manure plants should be selected on the basis of availability of healthy and cheaper seeds, ease to cultivate, high vigour and dry matter production with no/less and more competition with crop and weeds, respectively, high land coverage to check erosion and conserve soil moisture, short life span, high carbon sequestration potential *etc*.

Reasons for adoption of brown manuring

Brown manuring is receiving attention from the farmers and researchers in recent years due to its several advantages. This eco-friendly approach helps in substituting 25% of inorganic fertilizer (specially, nitrogen through BNF by leguminous brown manure plants) through supplying nutrition organically and thus, cuts down environmental hazards to an extent. Apart from supplying various macro and micro nutrients to the crop, it adds organic carbon to the soil and improves soil physical properties like soil structure, water holding capacity *etc*. Fallen leaves often act as surface mulch/cover and thus, saves evaporation water loss to an extent. Further, these residues get decomposed quickly and adds nutrients (specially, nitrogen) to the soil. As plants remain standing even after knock down with herbicide, it protects the light soil from erosion (Singh, 2014). Besides, it helps in enhancement of soil microbial activities (Behera *et al*., 2019). Along with the positive impact on soil health, it improves growth and yield of the crop by supplying nutrients and water and thereby, provides economic profitability to the farmers. Further, it captures land space and other resources, which, otherwise, are utilised by the weeds and reduces early weed growth due to its high growth rate and competition with weeds.

Impact of brown manuring in agriculture

Brown manuring, being an eco-friendly approach, plays a major role in improving agricultural productivity in a sustainable manner through weed management, sequestration of carbon, biological nitrogen fixation, addition of macro and micro nutrients to soil, saving soil moisture, improving physical, chemical and biological properties of soil *etc*. In this section, impact of brown manuring on weed management, soil health and plant nutritional quality, growth and yield of crop and production economics as reported from various research works has been briefly described.

Weed management

Weed is a great menace to crop and competes with the crop at below and above ground for resources. Elevation in crop productivity requires effective weed management strategy to be implemented. Single approach is not always efficient in weed management. For instances, application of herbicide kills the weed, but leaves toxic foot prints in the environment. Further, manual weeding is not feasible everywhere specially, under labour unavailability. Therefore, integrated weed management (IWM) combining manual, mechanical, chemical, biological and cultural approaches of weed management is needed. Brown manuring, being a cultural approach, holds good prospect solely or as a part of IWM specially, for controlling weeds of DSR. However, it also effectively controls weeds of other crops like maize, sugarcane *etc*. Various research works as shown in Table 1, indicates the beneficial role of brown manure in weed management. Brown manure can suppress or smother weeds by occupying land space and early accumulating dry matter (DMA) or shading through greater canopy coverage. Besides, during decomposition of brown manuring plants, certain organic acids and allelochemicals are secreted which reduce size of weed seed bank. It is notable that brown manuring is more effective in suppressing broad leaved weeds and sedges than grasses (Kumar and Ladha, 2011).

Table 1: Brown manuring as weed management option in various crops.

Weed management option	Crop and impact	References
PE pendimethalin+sesbania brown manuring (BM)+hand hoeing at 90 DAP	Lowest weed density and dry weight and 82.3% weed control efficiency (WCE) in sugarcane	Fanish and Ragavan, 2020
PE pendimethalin @1 kg/ha+sesbania BM+ 2,4-D @ 0.5 kg/ha at 25 DAS	Lowest weed dry matter in DSR	Chongtham *et al*., 2015
Sesbania BM	Higher yield of DSR than that without BM and comparable with transplanted rice	Sharma *et al*., 2017
	Reduction of weed density in DSR	Chaudhary *et al*., 2018
	Reduction of total weed biomass by 40-50% in DSR	Singh and Singh, 2007
	Reduction of weed density by 41-56% and dry biomass by 62-75% in DSR	Nawaz *et al*., 2017
	50% WCE at 25 DAS in maize	Tanwar *et al*., 2010
	Lowest weed count/m^2 and weed biomass in wet DSR	Gangaiah and Babu, 2016
Sesbania and cowpea BM	Reduction of weed density in DSR	Yadav *et al*., 2014
PE alachlor @ 1 kg/ha+BM	Lowest weed density up to 45 DAS and 89.6% WCE in *rabi* maize	Ramachandran *et al*., 2012 Maity and Mukherjee, 2011
PP Butachlor @ 1.5 kg/ha+BM+2, 4-D @ 0.5 kg/ha at 40 DAS	Lowest weed dry weight and highest WCE (86-88%) in DSR	
Sesbania knocked down by 2.4-D @ 0.5 kg/ha at 30 DAS	Reduction in weed density by 37-42% in DSR	Singh *et al*., 2009a
Sesbania knocked down by 2.4-D @ 1kg /ha at 30 DAS		Anitha and Mathew, 2010
Drum seeding+sesbania BM	Reduction in weed density and DMA in rice	Prabhakara and Chinnusamy, 2006
Drum seeding+sesbania BM (one row) between two paired rows of main crop		Bhambri and Kolhe, 2006
Sun hemp BM (two rows) between the rows of main crop	Lowest weed dry weight and 77.97% WCE in maize	Ajamirali, 2017
Intercropping of BM plants	Reduction of weed density by 40-50% in rice	Rehman *et al*., 2007
Sesbania BM plant's leaves as mulch	Reduction of weeds in rice	Mahajan *et al*., 2009
PE pendimethalin @ 1kg/ha+sesbania BM (intercrop)+hand weeding at 20 DAS	Reduction of weed population in upland DSR	ICAR, 2007
Intercropping of sesbania BM plants for 30 days	Equally effective in controlling weeds of dry seeded rice as wheat residue mulch @ 4 t/ha	Singh *et al*., 2007
Sesbania knocked down by 2,4-D at 25 DAS	Reductions of broad leaved weed density by 36.5% and 67.3% and total weed biomass by 56.8% and 43.4% at 35 and 70 DAS, respectively in maize	Shekhawat *et al*., 2021
PE pendimethalin @ 750 g/ha+BM (5 WAS) +POE bispyribac sodium @ 25 g/ha.	Reduction of weed density and dry biomass in DSR	Kumari and Kaur, 2016

PE = Pre emergence application, PP= Pre plant application, POE= Post emergence application, DAP= Days after planting, WAS= Week after sowing.

Soil health and plant nutritional quality

Brown manure, not only acts as a weed management option, but also plays an important role in improving soil health. Since, it sequesters carbon as well as fixes atmospheric nitrogen into the soil, it enriches soil physico-chemical properties such as improvement in organic carbon, hydraulic conductivity, soil structure and reduction of bulk density (Hamza and Anderson, 2005). It also accelerates microbial activities in soil. Sharma *et al*. (2017) observed higher actinomycetes population in BM applied plots of basmati rice grown under system of rice intensification. Zero tillage along with sesbania BM (knocked down by 2,4-D @ 625 g/ 500 litres at 35 DAS) in rice increased organic carbon, hydraulic conductivity and reduced bulk density (Singh *et al*., 2009b). Nawaz *et al*. (2017) reported increase of nitrogen, organic carbon, microbial biomass carbon and microbial biomass nitrogen and reduction of bulk density of soil under BM application in DSR. Samant (2017) also found improvement of soil organic carbon and nitrogen after harvest of rice through brown manuring. Khan (2013) observed increase of soil organic carbon through brown manuring by 0.03-0.05%. Improvement of soil organic carbon through brown manuring was reported by many other researchers also (Satyaprakash and Poolchand, 2011; Sarangi *et al*., 2016). Further, Kwesiga *et al*. (1999) and Orwa *et al*. (2009) reported BNF properties of brown manuring plants. Apart from nitrogen and carbon, it also supplies various macro and micronutrients for the plant uptakes. Singh *et al*. (2009a) and Chaudhary *et al*. (2018) used brown manuring in DSR and observed increments of nitrogen, phosphorus and potassium in soil. Pandit *et al*. (2020) also found improvement of post-harvest available nitrogen, phosphorus and potassium in soil by applying 75% recommended dose of fertilizer (RDF)+FYM @ 5 t/ha+ sesbania BM in DSR. Gangaiah and Babu (2016) observed that brown manuring with *Sesbania aculeata* improved uptakes of nitrogen, phosphorus and potassium by rice over no brown manuring. Venkata Lakshmi and Veeraraghavaiah (2015) also reported improvement in nutrient uptakes by rice through brown manuring with Glyricidia. In another study, use of PE pendimethalin @ 750 g/ha+BM (4 WAS)+POE bispyribac sodium @ 25 g/ha improved nitrogen uptakes by grain and straw of DSR (Kumari and Kaur, 2016). As brown manuring improves nutrient uptakes specially, nitrogen, it exerted positive impact on grain quality. Chongtham *et al*. (2015) observed improvement of grain protein content of DSR through integrated application of herbicide and brown manure. Brown manuring can also break soil crust and helps seedlings to emerge. Brown manuring improves nutrient and water use efficiencies. Maity and Mukherjee (2011) reported that application of PP Butachlor @ 1.5 kg/ha+BM+2, 4-D @ 0.5 kg/ha at 40 DAS improved nutrient use efficiencies (N, P and K) in DSR. Sharma *et al*. (2008) achieved 43.6% water saving in DSR over transplanting by using sesbania co-culture. Singh *et al*. (2009a) also noticed 39.4% water saving by using brown manuring in DSR over transplanting. In another study, Ajamirali (2017) observed high water use efficiency in maize under sun hemp brown manuring. Besides, brown manuring acts as a mulch as well as on decomposition, improves soil porosity and water holding capacity (WHC) and thus, it conserves the soil moisture for crop's availability. Ramachandran *et al*. (2012) noticed improvement of soil moisture through application of PE alachlor @ 1 kg/ha+sesbania BM in maize due to weed suppression and improvement of soil WHC by brown manuring.

Crop growth and yield

Positive impacts of brown manuring on soil as well as weed management directly reflect on crop growth and yield. It is because of the improvement of soil health which adequately supplies nutrients and moisture to the crop as well as saving the resources for the crop through suppression of weeds. Gangaiah and Babu (2016) reported increase of DMA by 38 g/m^2 and yield by 0.15 t/ha through brown manuring over no BM. Fanish and Ragavan (2020) used PE pendimethalin +sesbania BM+hand hoeing at 90 DAP in sugarcane and observed 38% higher yield than unweeded control. Shekhawat *et al*. (2021) observed improvement of maize yield through sesbania BM. Maity and Mukherjee (2011) obtained highest grain and straw yields of DSR by applying PP butachlor @1.5 kg/ha+BM+2,4-D @ 0.5 kg/ha at 40 DAS. Kumari and Kaur (2016) used PE pendimethalin @ 750 g/ ha+BM (5 WAS)+POE bispyribac sodium @ 25 g/ha and found high plant height, tiller number and biological yield of

Table 2: Yield, harvest index and economics of rice as influenced by brown manuring over farmer's traditional practice (Samant, 2017).

Year	Grain yield (q/ha)		Straw yield (q/ha)		Harvest index (%)		Production efficiency (kg/ha/day)		BM				FP			
	BM	FP	BM	FP	BM	FP	BM	FP	Cost of cultivation (₹/ha)	Gross return (₹/ha)	Net return (₹/ha)	B:C	Cost of cultivation (₹/ha)	Gross return (₹/ha)	Net return (₹/ha)	B:C
2014	31.8	27.3	34.0	28.7	48.3	48.7	30.2	26.0	30,430	46,648	16,218	1.53	29,450	39,998	10,548	1.36
2015	28.6	24.7	33.2	29.4	46.3	45.7	27.2	23.5	31,130	43,644	12,514	1.40	30,125	37,767	7,642	1.25
Mean	30.2	26.0	33.6	29.0	47.3	47.2	28.8	24.8	30,780	45,146	14,366	1.47	29,787	38,882	9,095	1.31

BM = Brown manuring, FP = Farmer's practice.

DSR. Samant (2017) in a study, reported higher yield, production efficiency and harvest index of rice by applying brown manuring than farmer's practice (Table 2). Pandit *et al*. (2020) obtained higher plant height, effective tillers, panicle length, filled grains/panicle and yield of DSR by applying 75% RDF+FYM @ 5t/ha+sesbania BM than 100% RDF. Increase of growth and yield of DSR through brown manuring was also reported by many other researchers (Chaudhary *et al*., 2018; Sarangi *et al*., 2016; Gill and Walia, 2013; Anitha and Mathew, 2010; Singh *et al*., 2009a; Aslam *et al*., 2008; Sharma *et al*., 2008; Ravisankar *et al*., 2008). Seema *et al*. (2015) observed improvement of yield of aerobic rice using sesbania brown manuring.

Production economics

Economic profitability is the ultimate goal of a farmer. Improving crop productivity by fetching less cost of cultivation asks for those technologies which are cheap but effective. Unlike green manuring, brown manuring requires very less intercultural operation as no incorporation of plant parts into the soil is required and thus, saves labour wages to an extent. Besides, it can substitute certain part of inorganic fertilizer as it supplies nutrients specially, nitrogen and saves the cost of substituted fertilizer. Sarangi *et al*. (2016) observed substitution of 25% of nitrogenous fertilizer by brown manuring. Being organic in nature, it improves soil health and helps the crop to uptake nutrients and water for its development. Further, brown manuring, suppresses the weeds and channelizes the resources only towards crop growth and productivity. All these benefits of brown manuring reduce the cost of cultivation and improve crop productivity and consequently, increase economic profitability of crop cultivation. Ramachandran *et al*. (2012) reported highest net return and benefit-cost ratio (B:C) by applying PE alachlor @ 1kg/ha+BM in maize. Fanish and Ragavan (2020) achieved highest net return and B:C through application of PE pendimethalin+sesbania BM+hand hoeing at 90 DAP in sugarcane. In DSR, application of PP Butachlor @ 1.5 kg/ha+sesbania BM+2, 4-D @ 0.5 kg/ha increased economic profit (Maity and Mukherjee, 2011). Pandit *et al*. (2020) obtained higher net return by applying 75% RDF+ FYM@ 5t/ha+sesbania BM than 100% RDF in DSR. Samant (2007) observed less cost of cultivation and higher gross return, net return and B:C under application of brown manuring than farmer's practice (Table 2). Gangaiah and Babu (2016) also noticed improvement in economic return in DSR through brown manuring.

CONCLUSION

Review of various research works above reveals that brown manuring holds very good prospects in suppression of weeds as well as improvement of soil health and thereby, can elevate crop productivity and profitability in an eco-friendly way. However, very less research works have been carried out on brown manuring and most of the works have been restricted to direct seeded rice only. Therefore, its wider adaptability across the location, season and crop is still to be explored. To investigate this further as well as for future recommendation to the farmers, multi-locational, multi-seasonal and multi-crop trials using different types of brown manure plants at different dose and duration of co-culture are needed at this hour from the researchers. Besides, extension service should be strengthened enough to transfuse this promising organic/eco-friendly approach to grass-root levels of farming community for achieving sustainability in agricultural production.

Conflict of interest: None.

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