Plant Archives Vol. 25, No. 2, 2025 pp. 269-282 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.v25.no.2.039

GREEN MANURE AS ORGANIC SUBSTRATES IN SOILLESS CULTURE: A SUSTAINABLE APPROACH

Mukesh Kumar[1*], Neetu Kataria[1] and Rajesh Kumar[3]

[1]Department of Botany, Government College, Bahadurgarh, Jhajjar - 124 507, Haryana, India.
[2]Principal, Government College, Bahadurgarh, Jhajjar - 124 507, Haryana, India.
*Corresponding author E-mail : mukbot23@gmail.com
(Date of Receiving-30-05-2025; Date of Acceptance-11-08-2025)

ABSTRACT

Green manure, as a natural, cost-effective and environmentally friendly cover crop, is crucial for enhancing soil quality, ensuring food security and promoting sustainable agriculture. It improves soil's physical, chemical, and biological properties. Legumes, a key type of green manure, can fix a significant amount of atmospheric nitrogen, up to 80-100 kg in 45-60 days. Their easy decomposition increases soil organic carbon, nutrient availability, and overall soil health, ultimately boosting crop productivity. Green manure can also be utilized as a dry powder substrate in soilless culture, a modern farming method with the potential to address global challenges like water scarcity, environmental pollution, and ecosystem instability. Soilless culture optimizes crop growth and yields high-quality produce with less land, thereby increasing land productivity. To facilitate the transition towards sustainable agriculture, governments should actively promote green manure technologies through economic incentives, technology extension, and educational programs. This review aims to explore and maximize the use of green manure as an alternative grow-media substrate within the emerging soilless farming sector, leveraging its technological innovation to drive sustainable agricultural development worldwide.

Key words : Green manure, Crop yield, Ecosystem, Soilless farming.

Introduction

The world's population is growing and is expected to reach 9.7 billion by 2050 (Desa, 2022). This will necessitate at least 50% and 70% increase in food supply by 2030 and in the subsequent four decades respectively (Velazquez-Gonzalez *et al.*, 2022). However, due to urbanization, population growth and industrialization, the land available for food production is expected to shrink by 1/3 of its current availability (Fig. 1) (Unicef, 2018). In response to the growing population, the newer technologies are focused on integration of food production technologies to aid the transition in agriculture (Tzortzakis *et al.*, 2020). Soilless culture is an emerging and promising technique for overcoming current agricultural threats. It is also the most sustainable and environmentally acceptable alternative to traditional soil-based intensive agriculture and is now regarded as a convenient approach for the conservation of energy, fertilizers, and water. In closed soilless systems, the most significant challenges are the saline level of the recirculating solution, uneven supply of the nutrients, control of the root pathogens, removal of undesired and potentially harmful compounds (Schwarz *et al.*, 2009).

Green manuring practices have become mainstream over the last three decades. They can be valuable strategies for better long-term sustainability of agriculture with very few risks to the environment (Kumar *et al.*, 2014). Green manures (GM) which are high in N and P can be easily decomposed and are useful in the for grow-media culture in the form of dry powder substrates (Elakiya and Arulmozhiselvan, 2021). This is the reason for the review to gather details that would enable the composition, rates and placement of GM crops to be designed so that precise and holistic agricultural strategies can be developed to manage the adaptation constraints of GM-based cropping systems and the use of green manures dry powder as soilless culture substrates.

Utilization of organic substrates for soilless culture

The modern greenhouse industry is witnessing advancements in soilless culture systems due to their numerous benefits. The greater use of renewable organic materials as soilless media is becoming important throughout the world over the last fifty years (Schmilewski, 2007) because of the eco-friendly nature of these materials. 'Soilless culture' as a concept is defined as any technique which does not use soil as a rooting medium for the cultivation of plants (Gruda *et al.*, 2016). The production of agricultural and horticultural crops is achieved soilless culture al technology (Fussy and Papenbrock, 2022). This involves soil-less crop production within a sealed environment, protected horticulture and vertical farming. The main benefits of soilless culture, which helps increase crop productivity and decreases labor, include absolute control over the supply of water, nutrients, pH, and temperature. Common soilless culture can harvest their crops in a short duration of eight to ten weeks.

There are two divisions in the soilless crop production system: (i) water-based culture which includes Deep Water Culture (DWC by Gericke 1929), float hydroponics (developed by University of Arizona, 1860), nutrient film technique (NFT, Allen Copper, 1965), and aeroponics (suggested by Richard Stoner, 1983) (Karagoz *et al.*, 2022) and (ii) substrate-based culture where the nutrient or substrate growing media is used. The soilless systems not only allow the optimization of the physical and chemical factors in the root environment, but also aid in the efficient management of pathogens. This fosters greater production yields at lower production costs (Gruda *et al.*, 2018). Growing media has been used for the cultivation of high-value vegetables, ornamental plants, and in plant propagation. Growing media or substrates are termed as all solid materials, other than soil, which in mixtures or alone can guarantee plant growth better than agricultural soil in one or many aspects.

Organic substrate culture employs natural organic nutrient substrates such as peat, coir, plant waste, sawdust, bark, rice hulls, rice husk, rice straw, compost, vermicompost, meal, cake, farm yard manure (FYM), coco peat, brick shards, bio control agents, bio fertilizers, paper waste, wood sawdust, peat moss, sphagnum moss, bagasse or natural substrates such as sand, gravel, tuff, pumice, perlite, rock wool, vermiculite, monmonorillite, and so on. Peat, compost, bark and wood wastes are the most widely available and useful organic resources. Growing swamp rose mallow in containers with vermicompost enhanced plant dry weight (McGinis *et al.*, 2009). Vermicompost mixed with coir in 2:1 ratio as container substrate increased plant height and fresh weight in *Beta vulgaris* L. (Abbey *et al.*, 2012). Bhat *et al*. (2013) revealed that substrates containing vermicompost, coco-peat, perlite and sphagnum peat moss produced significantly better growth, yield and quality in tomato, cucumber and capsicum than other substrate combinations. Kameswari *et al*. (2014) obtained highest values of plant height, plant spread, number of branches per plant, duration of flowering, flower weight, spray length and number of flowers per plant were in the potting media containing cocopeat + sand + FYM+ vermicompost.

Different substrates were evaluated for soilless culture in watermelon, and the plant growth, yield, fruit quality, and plant nutrient uptake were highest with vegetative growth in basaltic mix, sand, peat, and greenhouse soil, respectively, with the maximum yield in perlite (Yetisir *et al*., 2006). Majdi *et al*. (2012) discovered that peat and perlite had the greatest effect on green pepper growth features and yield. Huang *et al*. (2020) investigated the combined effects of biochar and vermicompost amendments on basil and tomato plant growth. Plants grown in Biochar: Vermicompost: Peat

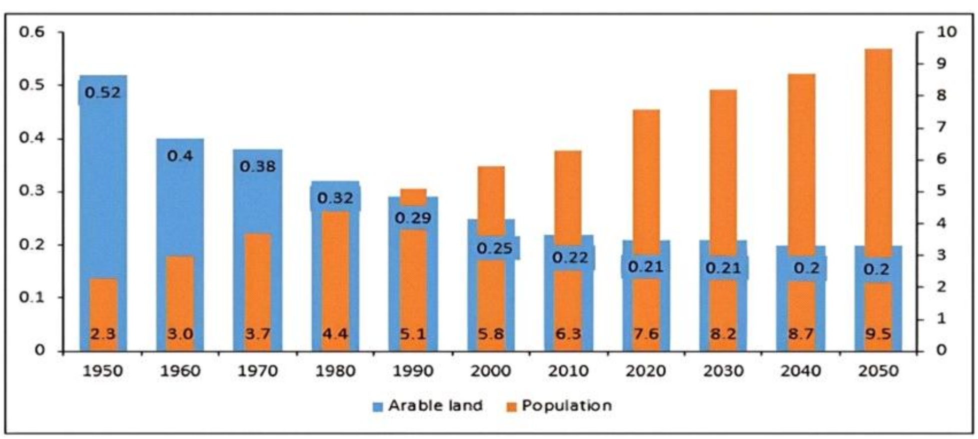


Fig. 1 : World population (billions) versus arable land (ha per person) 1950-2050 (Gupta *et al*., 2021).

Table 1 : Categories of green admixture crops (Maitra *et al*., 2018).

Legume crops	**Non-grain, aroma and beat legumes**	
Pigeon pea (*Cajanus cajan)*	Sunn hemp (*Crotalaria juncea*)	Subclover (*Trifolium subterraneum*)
Green gram (*Vigna radiata*)	Dhaincha (*Sesbania* species, *S. aculeata*)	Strawberry clover (*T. Fragiferum*)
Cowpea (*Vigna unguiculata*)	Wild indigo (*Tephrosia purpurea*)	Persian clover (*Trifolium resupinatum*)
Soybean (*Glysine max*)	Black henna (*Indigofera tinctoria*)	Red clover (*Trifolium pratense*)
Groundnut (*Arachis hypogea*)	Barseem (*Trifolium alexandrinum*)	White clover (*Trifolium repens)*
Cluster bean (*Cyamopsis tetragonoloba*)	Broadbean (*Vicia faba*)	*Desmodium*
Sub-tropical grasses and weeds	White lupin (*Lupinus albus*)	*Centosemia*
Panicum maximum	Blue lupin (*Lupinus angustifoilus*)	*Stylosanthes*
Pennisetum purpureum	Yellow lupin (*Lupinus luteus)*	
Tripsacum laxum	Common vetch (*Vicia sativa*)	
Aduthoda vesica	Fenugreek (*Trigonella foenumgraecum*)	
Eicchornia crassipes	Candied clover (*Melilotus spp*.)	
Trianthema portulacastrum	Trefoil (*Lotus spp.)*	
Ipomoea carnea	Black medic (*Medicago lupulina*)	
Calotropis gigantea	Lucerne or alfalfa (*Medicago satvia*)	
Green Leaf manures		
Leucaena leucocephala (Subabul)	*Azadirachta indica (*neem)	*Tephorsia candida*
Gliricidia spp.	*Derris indica*	*Dodonea viscosa*
Cassia siamea (Kassod tree)	*Cassia tora*	*Hibiscus viscosa*
Cassia auriculata	*Cassia accidentalis*	*Delonix elata*
Delonix regia	*Peltophorum ferrugenum*	*Cassia nigricans*

substrate had identical growth indexes and total dry weight to those grown in 100% Peat substrate, according to the findings.

Scope of utilizing organic substrates in soilless crop production

The stability of soil organic matter is dependent on the long-term input of organic materials to soils through the integration of crop wastes and organic manures, as well as the proper biological activity. The formation of particulate organic matter in an accountable proportion plays important roles in continuous cropping systems where integrated nutrient management practices are carefully implemented. Prevailing agro-climatic conditions also promote the buildup of particulate organic matter. The process of recycling organic matter in soils is long-term. The use of organic resources for agricultural production has remained viable in recent years, notably in containerized crop farming. Finding the right combination of organic materials to make effective growing media for anchoring roots and providing adequate water and nutrients to plants is critical.

Green manuring crops

Green manuring is the action of agronomic practices and the assimilation of legume and non-legume green plants into the soil, either in situ or by introducing plants developed abroad and congenital into the soil for abundance improvement. Green manures are created by integrating green plant materials (such as freshly cut weeds or crop rotation detritus) into soil. Green admixture crops can comprise legumes, non-grain, aroma, and beat legumes, abiding coarse multifunctional shrubs, and crops ideal for green leaf manuring (Table 1).

Legume crops and tree species suitable for green manuring in different agro-climatic zones are mentioned in Table 2 and nutrient composition of some of the green manures and green leaf manures are given in Fig. 2. and some of common green manures and green leaf manures of tropical region are depicted in Figs. 3 and 4.

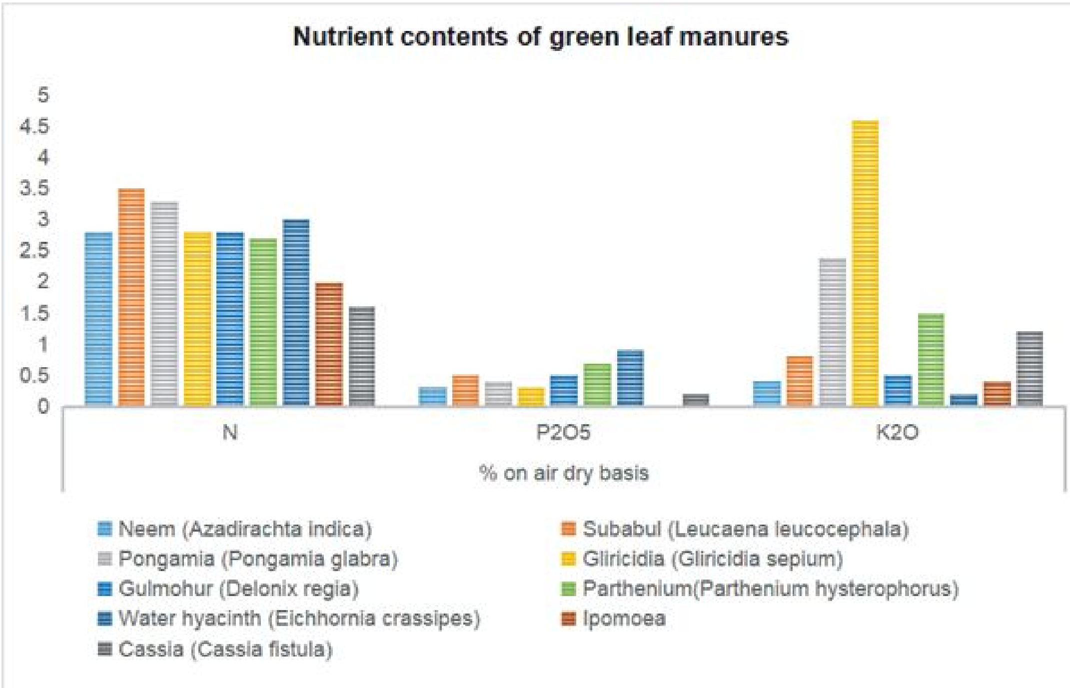


Fig. 2 : Nutrient content of green manures.

Nitrogen contribution by green manuring

Green manure nitrogen is superior to urea nitrogen in terms of plant growth and development, as well as crop grain output (Singh *et al*., 1991).

Green manure nitrogen supply is not immediate; it is a gradual and delayed process. Green manuring crops not only fix dinitrogen in the atmosphere, but they also aid to conserve nitrogen in soil. The decomposing plant offers nutrients for crop growth via green manuring, decreasing the need for chemical fertilizer during the juvenile stage. Green manures improve soil qualitative attributes with equivalent efficiency to min fertilisers, whereas mineral fertilisers degrade soil conditions. However, actual information on the pace of breakdown and the amount of nutrients released by daincha inclusion is limited (Munawar and Suhartoyo, 2013). Table 3 displays some green manuring crops and their nitrogen contributions.

The soil nutrient balance after incorporation of different green manures specially *S. rostrata*, *S. aculeata* and *C. juncea* exhibited positive balance of nutrients than other green manures (Irin *et al*., 2019). While evaluating the effect of different in-situ green manuring on soil organic matter (%), N (%), P (ppm) and K (meq/100 gm) contribution on pre-sown rice soil in 2015 and 2016, Irin and Biswas, 2023 concluded that after two consecutive year, Green Manure-Transplant Aman-Mustard Cropping Pattern increased soil organic matter, nitrogen, phosphorus and potassium compared to initial soil by which N fertilizer rates could be reduced after the incorporation of green manures in the succeeding and following crops (Fig. 6).

Green manure's contribution of additional nutrients

Green manures, particularly those with deep roots, extract nutrients from deeper layers and make them available after decomposition. Green manuring crops release and recycle nutrients (nitrogen, phosphorus and potassium) during decomposition, assisting in integrated plant nutrition management. Phosphorus availability is typically reduced in calcareous and acidic soils due to interaction with calcium carbonate and iron oxide (Oehl *et al*., 2001). Phosphorus release during decomposition is usually associated with phosphorus levels in green manure. During the degradation of plant biomass, approximately 40 to 60 percent of the phosphorus is immediately released.

In organically managed system, mineralization of available organic phosphorus in soil is the primary source of phosphorus. The phosphorus in the soil has to be made available to the plants (Oehl *et al*., 2001). Green manure absorption into soil improves the phosphorus cycle and increases the availability of sparingly soluble phosphorus (Cavigelli and Thein, 2003). Green manure crops collect a considerable amount of P, which decomposes into bicarbonates (H_2CO_3). This bicarbonate can solubilize soil mineral P, ensuring sufficient phosphorus for subsequent crops (Sharpley and Smith, 1989; Tissen, 1994).

Pueraria
Pueraria phaseoloides

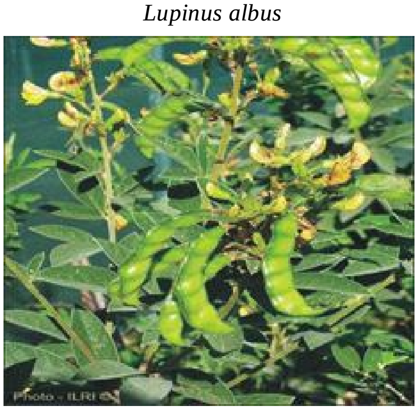
Green gram
Pueraria phaseoloides

Lablab
Lablab purpureus

Dhaincha
Sesbania aculeate, S. rostrata

White lupin
Lupinus albus

Berseem
Trifolium alexandrinum



Pigeon pea
Cajanus cajan

Sunn hemp
Crotalaria breviflora, C. juncea, C. striata

Fig. 3 : Green manures of tropical region.

Fig. 1 continued...

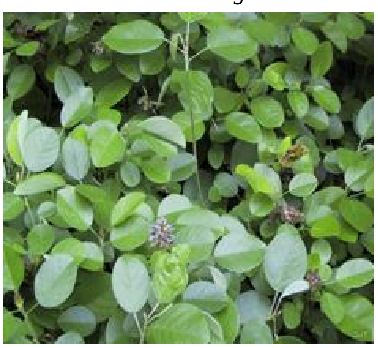
Fig. 1 continued...

Buffalo bean
Mucuna aterrima

Jack bean
Canavalia ensiformis

Velvet bean
Mucuna deeringiana

Stylo
Stylosanthes guianensis



Desmodium
Desmodium ovalifolium

Milk vetch
Astragalus sinicus

Zornia
Zornia latifolia

Jumby bean
Leucaena leucocephala

Addition of green manures increase the soil organic carbon subsequently leading forward to reduction on soil pH. This decrease in soil pH reduces the phosphate fixation in soil with iron and aluminium (Gu *et al.*, 2023). Ultimately availability of phosphous increases. Lupins grown in phosphorus deficient soil were found to extrude protons and different organic acids (Shen *et al.*, 2005; Sas *et al.*, 2001). Green manuring uplifts the P uptake of

Table 2 : Leguminous green manure crops for different regions (Meena *et al*., 2018).

(A) *In situ* green manure crops			
(a) Tropical region		**(b) Temperate region**	
Common name	**Scientific name**	**Common name**	**Scientific name**
Cluster bean	*Cyamopsis tetragonoloba*	Subterranean clover	*Trifolium subterraneum*
Cowpea	*Vigna unguiculata*	Ladino clover	*Trifolium repens*
Pueraria	*Pueraria phaseoloides*	Crimson clover	*Trifolium incarnatum*
Green gram	*Vigna radiata*	Faba bean	*Vicia faba*
Lablab	*Lablab purpureus*	Soybean	*Glycine max*
Dhaincha	*Sesbania aculeate, S. rostrata*	Red clover	*Trifolium pratense*
White lupin	*Lupinus albus*	Black lentil	*Lens culinaris*
Gray bean	*Mucuna cinerecum*	Alfalfa	*Medicago sativa*
Pigeon pea	*Cajanus cajan*	Barrel medic	*Medicago truncatula*
Sunn hemp	*Crotalaria breviflora, C. juncea, C. striata*	Hairy vetch	*Vicia villosa*
Buffalo bean	*Mucuna aterrima*	Milk vetch	*Astragalus sinicus*
Jack bean	*Canavalia ensiformis*	Winter pea	*Pisum sativum*
Velvet bean	*Mucuna deeringiana*	Sweet clover	*Melilotus officinalis*
Stylo	*Stylosanthes guianensis*	Cura clover	*Trifolium ambiguum*
Desmodium	*Desmodium ovalifolium*	Purple vetch	*Vicia benghalensis*
Milk vetch	*Astragalus sinicus*	Common vetch	*Vicia sativa*
Zornia	*Zornia latifolia*	**(B) *Ex situ* green leaf manuring shrubs and trees**	
Jumby bean	*Leucaena leucocephala*	**Common name**	**Scientific name**
Kudzu	*Pueraria phaseoloides*	Subabul	*Leucaena leucocephala*
Adzuki bean	*Vigna angularis*	Gliricidia	*Gliricidia sepium*
Black gram	*Phaseolus mungo, P. trilobus*	Karanj	*Pongamia glabra*
Soybean	*Glycine max*	Milkweed	*Calotropis gigantea*
Alfalfa	*Medicago sativa*	Tephrosia	*Tephrosia purpurea*
Wild indigo	*Indigofera tinctoria*	Wild indigo	*Indigofera teysmannii*
Berseem	*Trifolium alexandrinum*	Sesbania Kassod	*Sesbania speciosa, S. rostrata* *Cassia tora*

succeeding crops by converting the fixed phosphorus into readily available forms (Cavigelli and Thein, 2003). Phosphorous deficiency stimulates the formation of cluster roots in green manuring crops which are more active in P mobility and uptake (Sas *et al*., 2001). In waterlogged conditions, green manures increased the availability of P through the mechanism of reduction, chelation and favourable alteration in soil pH. Higher availability of phosphorus from rock phosphate was reported due to green manuring in the rice fields (Cavigelli and Thein, 2003).

The extensive root system of green manure crops improved the physical condition of the soil and liberated CO_2 and organic acids, which help in dissolving native potassium in soil and thereby increases the availability of potassium and per cent increase noticed was 2.1 to 4.9% (Rani *et al*., 2020). Incorporation of *Sesbania aculeata* and *Crotalaria juncea* with N significantly increased soil organic carbon, N, P, K, Ca and S (Islam *et al*., 2019) (Table 4).

Green manure crops can fix up to 153 kg K/ha and up to 20 kg P/ha (Talgre *et al*., 2012). Dhaincha and green gram increased the soil available potassium by 3.7 and 2.4 per cent, respectively. P and K utilization to an

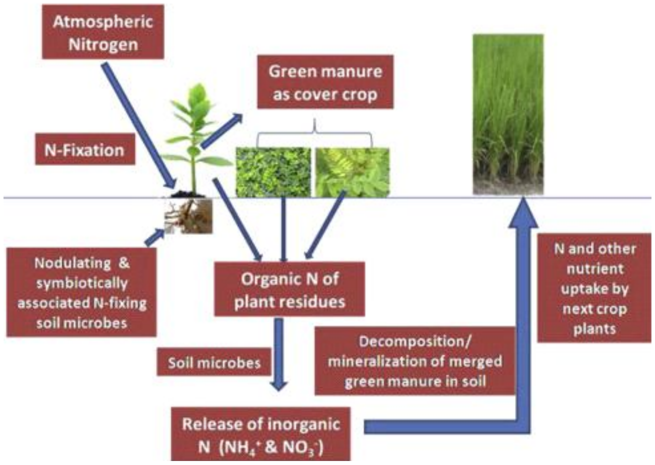


Fig. 4 : Role of green manure crops in management of soil nitrogen.

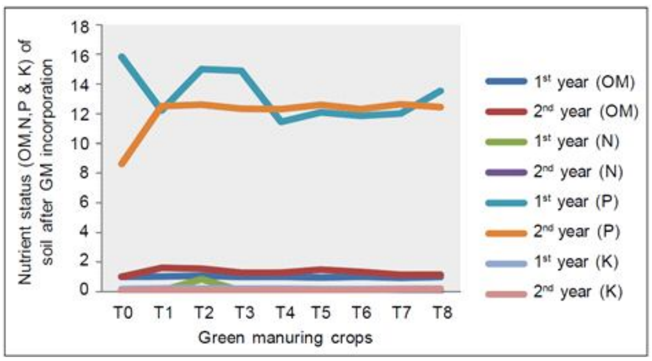


Fig. 5 : Effect of *in situ* green manure incorporation on soil properties at two consecutive years (T_0 = Control, T_1 = *S. aculeata*, T_2 = S. *rostrata*, T_3 = *C. juncea*, T_4 = *V. radiata*, T_5 = *V. mungo*, T_6 = *V. unguiculata*, T_7 = *L. leucocephala*, T_8 = *M. pudica*) (Sarwar, 2015).

extent of 10 to 12 per cent was observed in field conditions due to green manure incorporation. GM crops contain appreciable amounts of NPK including other trace elements also (Bhuiyan and Zaman, 1996). They also mobilize S, P, Si, Zn, Cu, Mn and other nutrient element as a result of increased microbial activity (CO_2 formation) and decreased redox potential (Becker *et al*., 1992). Green manuring with *Sesbania rostrata* increased both availability in soil and accumulation in plant of Fe, Mn and Cu due to the development of intense reducing condition, complex formation and greater nutrient holding capacity (Bhatacharya and Mandal, 1996). Eriksen and Thorup-Kristensen (Rumball, 1986) found that cruciferous crops such as winter rape or fodder radish were particularly effective at preventing sulphur leaching into lower soil profiles. Green manures such as forage chicory accumulate large amounts of micronutrients including sulphur, boron, manganese, molybdenum and zinc (Rumball, 1986). Green manuring crops promote mycorrhizal growth on the roots of succeeding crops, increasing soil phosphorus (P) and micronutrient availability (MacRae and Mehuys, 1985). Soil P and K contents were highest in plot with Crotalaria, while soil Ca content was highest in plot with *Mucuna* (Carvalho *et al*., 2015).

The decomposition of daincha biomass increases humus, accessible nitrogen, and lowers the soil C:N ratio. The nutrient content of 60-day-old dhaincha plants contained 3% N in addition to K, Ca, Mg, P, S and micronutrients. The addition of 1.0 t ha-1 dhaincha biomass to soil resulted in approximately 33 kilogram N, 1 kg P, 14 kg K, 14 kg Ca, 16 kg Mg and 2 kg S. Across maize developmental stages, the green manuring treatment boosted dry matter accumulation and nitrogen uptake by 28-114% and 83% to 146%, respectively. Green manure treatment significantly increased soil organic carbon by 3.90–12.23% over all N application rates, and total nitrogen and available nitrogen were significantly increased by 3.79–15.76% and 4.87–17.29%, with total phosphorus and available phosphorus by 6.1–13.6% and 9.6–5.3% respectively during maize developmental stages in the North China Plain (Yang *et al*., 2018).

The number of filled grain/panicles and highest grain production (4t/ha) were obtained in the green manuring plot, owing to the projected gradual release of nitrogen available throughout rice growth. After three years of consistent green manuring, soil organic matter and N levels increased to 1.09% and 0.37%, respectively (Mann *et al*., 2000). The ability of diverse dhaincha accessions to produce biomass was responsible for an increase in soil organic matter (Sarwar, 2015). Root, leaf, and stubbles of dhaincha after decomposition increased the organic matter status of soil on green manuring due to that organic matter and total N status of soil varied from 1.42 to 1.58% from the original level 1.51% and from 0.075 to 0.098% from the initial level 0.078 percent, respectively after three years of continuous incorporation (Rahman *et al*., 2013).

When comparing the effects of different natural farming practices on black gram yield, the combination of Beejamrutha, Jeevamrutha, mulching and green manure treatment significantly improved growth and yield attributes, as well as yield (1.062 t/ha), which may be attributed to increased nutrient availability throughout crop growth, which was further ensured by improved microbial activity in the soil (Sutar *et al*., 2019). In a rice-based cropping system, the rice grain yield increased by 32 to 77% over the control due to the incorporation of daincha as green manure along with different doses of NPK fertilizers, which can be attributed to the efficient and adequate nutrient supply from daincha biomass decomposition and release nutrients for crop utility (Noor *et al*., 2015).

Table 3 : N accumulation in major leguminous green manure crops.

Crop species	Growth duration (days)	N accumulation (t ha^{-1})	Reference
Glycine max	45	0.13	Meelu *et al*. (1985)
Crotalaria juncea	45	0.19	
Cajanus cajan	45	0.04	
Sesbania aculeata	45	0.25	
Vigna radiata	45	0.08	
Dolichos lablab	45	0.07	
Indigofera tinctoria	45	0.05	
Sesbania rostrata	56	0.09	Furoc *et al*. (1985)
Sesbania aculeata	56	0.16	
Vigna unguiculata	45	0.08	
Vigna radiata	45	0.08	Morris *et al*. (1986)
Sesbania rostrata	60	0.24	Ladha *et al*. (1986)
Sesbania cannabina	60	0.18	
Sesbania aegyptiaca	57	0.04	Ghai *et al*. (1985)
Sesbania grandiflora	57	0.03	
Cluster bean	49	0.10	Singh *et al*. (1991)
Common vetch	Flowering	0.11-0.23	
Sweet clover	Flowering	0.16-0.33	
Milk vetch	Flowering	0.07-0.14	Watanabe (1984)

Among the organic manures, *Sesbania aculeata* played a vital role in improving the uptake of NPK due to quick release of N from the added green manure with increased availability of P through the mechanism of reduction and chelation at favourably changed soil pH, release of K through the priming effect and direct contribution of K by green manure (Geethalakshmi, 1996). Effect of incorporation of dhaincha biomass in soil was noticed in increased organic matter content and total nitrogen. The amount of organic matter content varied from 1.58 to 2.13 per cent before incorporation and 1.99 to 2.27 per cent after incorporation of dhaincha biomass in soil. Likewise, the total N in soil varied from 0.09 to 0.12 per cent before incorporation and 0.106 to 0.126 after incorporation (Sarwar *et al*., 2017). Status at the peak period of 50 days after incorporation and declined thereafter except in soil pH, K and S (Chanda *et al*., 2021).

Improvement in soil conditions on green manuring

Daincha incorporation as green manure improved the soil physical environment, made the soil softer indicated by reduced bulk density, increased porosity of soil, increased the availability of major nutrients and ultimately favoured in increased yield of rice (Ahmed *et al*., 2020). Further, green manuring with daincha crop improves soil structure, aeration, permeability and also protect leaching of nutrients from the soil. Green manuring effects on crop growth and nutrient utilization are associated with an improvement in soil physiochemical properties, such as bulk density, water conductivity, and carbon and N levels (Thorup-Kristensen *et al*., 2003; Mandal *et al*., 2003). Further, green manuring with daincha crop improves soil structure, aeration, permeability and also protect leaching of nutrients from the soil.

Soil water stored in 2-year *Sesbania* improved fallows was greater than in continuously cropped fertilized or unfertilized maize in eastern Zambia (Phiri *et al*., 2003). Incorporation of green manures reduced soil bulk density compared with the control and NPK fertilizer in consecutive years (Fig. 7). However, there were no significant differences in bulk density between Moringa, Pawpaw, Mesquite and Neem leaves used as green manure (Adekiya *et al*., 2019). Water-stable aggregate ratio (%) and carbon percent of soil macro-aggregates (>250 µm) and micro-aggregates (53 - 250 µm) in green manure treated plot were significantly higher than in NPK (Fig. 8). Thus, green manure promoted soil aggregation and stabilized carbon in soil aggregates confirming green manure supplies nutrient, improves soil carbon storage and soil physical stability (Lee *et al*., 2023).

Incorporation of green manures had slightly lowered soil pH compared with control and this decrease in soil

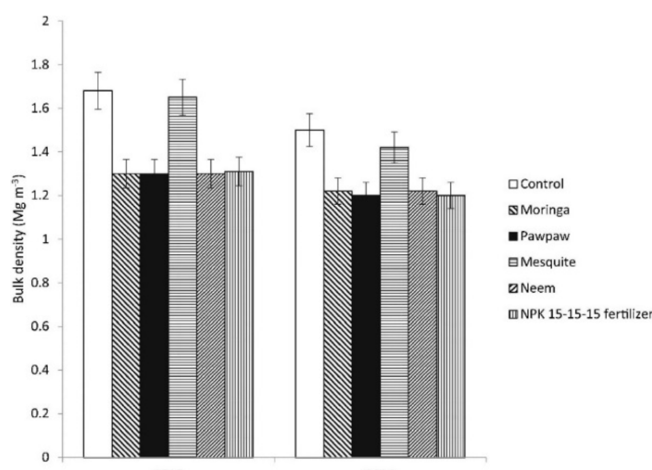


Fig. 6 : NPK fertilizer and other green manures' effects on soil bulk density.

pH may be due to production of CO_2 and organic acids during decomposition of incorporated green manures (Islam *et al.*, 2019) (Table 4). Reduction from initial soil pH (7.64 to 7.96) was observed after green manuring resulting to lower pH (7.47 to 7.88). The reduction in pH might be due to incorporated *Sesbania* leaves whose sap has a pH of 4.0 and strongly acidic in nature. After decomposition, a marked influence in neutralizing the high pH of soil occurred due to production of organic acids (Rani *et al.*, 2020; Adekiya *et al.*, 2019). Some other authors also reported that application of different types of green manures also decreased soil pH.

Salinity of the soil increases after adding green manure due to increase in cations and anions or increasing in release of salts and nutrients from decomposing biomass. Organic carbon content significantly improved by incorporation of *Sesbania* green manure upto 6.7 to 11.8 per cent over check. The status of available N was improved when *Sesbania* was incorporation at 45 days of growth from 2.7 per cent in check plots to 4.8 percent in daincha incorporated plots (Rani *et al.*, 2020).

Effect of green manuring on biological activity

Green manures promote soil microbial growth and activity, mineralization (Eriksen, 2005) and improve soil fertility and quality. Soil microbes decompose organic matter by producing numerous enzymes, which increases soil enzymatic activity (Kautz *et al.*, 2004). Green manure provides nutrients rich in organic carbon to the microbial biomass and increases the biodiversity of soil microorganisms, resulting in disease suppression and improved soil structure, soil properties, and crop health (Kumar *et al.*, 2014).

Soil microbial biomass carbon and nitrogen is an important index for assessing rhizosphere effect (Hu *et al.*, 2006). Green manures can supply nutrients for the reproduction of soil microbes, increasing diversity and making the environment suitable for new microorganisms to develop in that site. Green manure applications not only enhanced the amount of soil microorganisms, but also boosted soil enzymatic activities due to root exudations and the efficiency of soil nutrient transformation, which is all advantageous.

Due to soft and succulent nature, dhaincha plants decompose readily in soil within 60 days. The rate of decomposition is very rapid within one to two weeks after incorporation and then decline gradually (Swarup, 1991). Daincha fixes atmospheric nitrogen through legume-Rhizobium symbiosis and hence its accumulated nitrogen in above ground matter has the potentiality to enhance growth and yield of subsequent crops when incorporated and decomposed (Golam Sarwar, 2017). The increase in total N content of soil due to incorporation of daincha may be attributed to the mineralization of N green manure biomass due to greater multiplication of soil microbes, which could have converted organically bound N to inorganic form (Schwarz *et al.*, 2009) in rice-based cropping system (Ehsan *et al.*, 2014).

Mineralization of nutrients from decomposing green manure was initially very low later increased at a faster rate up to 5-7 weeks and thereafter declined with time (Rahman *et al.*, 2013). Green manure decay rates would increase when N contents were increased or would decrease if the N content declined (Shi, 2013). In wetland rice fields, 40 per cent of carbon and 80 per cent nitrogen of *Sesbania* mineralized in initial 10 days of incorporation while release of N was highest in the fifth week after incorporation (Selvi *et al.*, 2005). In another study, the peak N release occurred after 5-8 weeks of decomposition of green manure and declined thereafter. Decomposition rate becoming slow or declining after a certain period might be due to declined microbial activity controlled by soil temperature, oxygen, substrate availability and microorganism activity as well C:N ratio (Thonnissen *et al.*, 2000).

Green manure application, particularly when combined with organic fertilizers, increased alpha diversity in the soil bacterial community, whereas the fungus community showed the opposite tendency. It also changed the soil microbial populations during both the growth and incorporation phases, particularly the taxa involved in the carbon, nitrogen and sulphur cycles. Compared to fallow treatments, green manure application significantly raised microbial biomass carbon by 29.8%-72.9%, regardless of the kind of combination fertiliser used. Green manure increased urease activity by 35.6%-142.6% and â-glucosidase activity by 65.9%-172.9% compared to fallow treatments. However, it decreased catalase activity by 22.5%-55.6% (Xu *et al.*, 2023).

Ash, crude protein and crude fibre content in dhaincha contribute to increase the soil nutrients status (Chanda *et al.*, 2021; Kabir *et al.*, 2018). Histidine, arginine and aspartate are the most abundant amino acids produced in seed exudates of Sesbania. A number of bacteria can use amino acids such as arginine, histidine, glutamate, glutamine, alanine and alanine and other amino acids as a sole nitrogen source in the presence of a suitable carbon source (Liu *et al.*, 2019). Chanda *et al.* (2019) reported biochemical properties of *Sesbania* species indicating substantial content of ash (9.03%), crude fibre (25.57%), crude protein (18.22%), lignin (21.97%), holo-cellulose

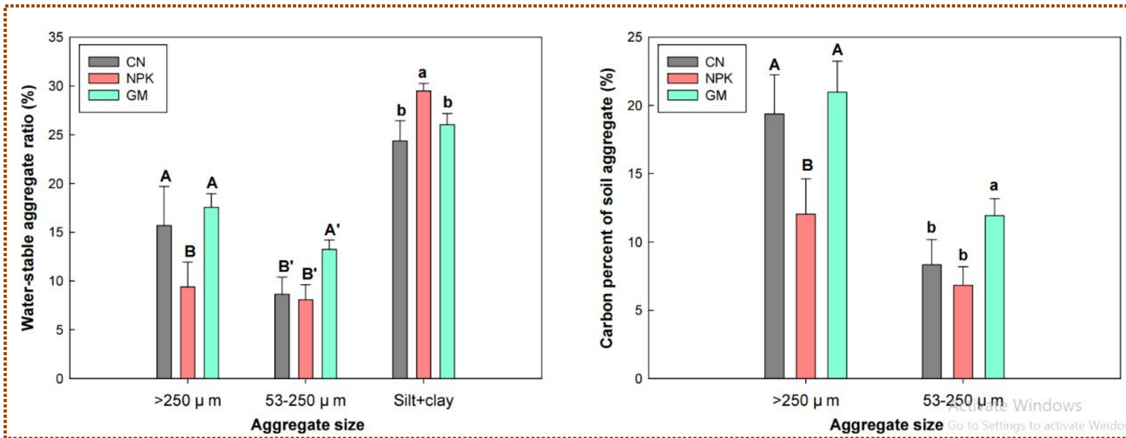


Fig. 7 : Distribution of water-stable aggregate and carbon of each fraction in treatments: CN, control; NPK, chemical fertilizer treatment; GM, green manure treatment (Lee *et al*., 2023).

Table 4 : Effect of green manuring crops and nitrogen levels on physical and chemical properties of postharvest rice soil (Islam *et al*., 2019).

Treatment	Bulk density (g/cc)	pH	OC (%)	Total N (%)	Available P (mg/kg)	Exchangeable K (meq/100 g soil)	Available S (mg/kg)
Initial value	1.35	5.76	0.81	0.064	4.86	0.138	21.21
Control	1.32	5.73	0.83	0.055	4.69	0.129	20.57
S. aculeata + N0	1.19	5.60	0.90	0.073	5.75	0.205	22.38
S. aculeata + N15	1.17	5.60	0.92	0.081	6.11	0.219	22.61
S. aculeata + N30	1.15	5.60	0.93	0.093	6.23	0.223	22.83
S. aculeata + N45	1.13	5.61	0.93	0.098	6.43	0.248	23.01
S. aculeata + N60	1.11	5.62	0.97	0.106	6.71	0.269	23.19
C. juncea + N0	1.19	5.61	0.89	0.069	5.86	0.194	22.53
C. juncea + N15	1.19	5.61	0.89	0.075	6.16	0.216	22.76
C. juncea + N30	1.17	5.62	0.90	0.088	6.38	0.219	22.91
C. juncea + N45	1.15	5.63	0.91	0.095	6.55	0.242	23.13
C. juncea + N60	1.12	5.62	0.94	0.103	6.83	0.261	23.36
N60	1.22	5.67	0.84	0.083	5.58	0.248	22.15
CV (%)	2.25	2.01	2.55	2.05	4.95	3.060	2.23
LSD (0.05)	0.04	0.19	0.039	0.003	0.51	0.011	0.28

(70.28%) and alpha-cellulose (41.22%). During four years of continuous experiment with ryegrass (*Loliummul tiflorum* L.) application to soil, soil microbial biomass carbon and nitrogen, soil respiration, soil enzymatic activities such as urease, invertase, and catalase were improved when compared to the control (Ye *et al*., 2014).

Potentials of green manure as a substrate and amendment

Green manures are also grown for animal fodder (Hossain and Becker, 2001), ground cover, firewood and other uses in traditional agro-forestry systems. To minimise chemical inputs in agriculture, green manure has been adopted preference over inorganic fertiliser (Thorup-Kristensen *et al*., 2003; Xie *et al*., 2016). Daincha is a popular and ideal green manure because of quick growing nature and its green matter is succulent and easily decomposable at low moisture content. On addition to soil, daincha can add significant amount of organic matter and nitrogen.

Advantageously many green manure crops grow well even in marginal lands with little or no input. Daincha can exhibit luxuriant growth in soil with a high salinity up to electrical conductivity of 10 dS m^{-1}. Due to this stability daincha and other few *Sesbania* spp. have been recommended for reclamation of saline and sodic soils (Chavan and Karadge, 1986). Long duration cultivation of dhaincha for about 10-12 year would eliminate desertification of marginal lands and hence its cultivation is recommended to rehabilitate degraded lands into productive crop lands (Carroll, 2009). Daincha crop has an annual yield potential of upto 20 tonnes of drymatter per hectare under appropriate production strategy (Carroll and Chris, 2009). At an dry matter production rate of 5.2 t ha^{-1} of Sesbania nitrogen equivalent to 135 kg ha^{-1} is produced (Ehsan *et al*., 2014).

Conclusion

Legumes such as *Sesbania aculeata*, *Sesbana rostrata*, *Vigna radiata* and *Vigna mungo* can serve as green manure crops because they can form nodules and fix nitrogen. The use of green manure crops not only boosted soil organic matter, nitrogen, phosphorus, potassium, and sulfur in the soils over their initial value, but also achieved peak levels at 50 days post incorporation. Because of this, the use of green manures in powder form as dry supplements mixed with other grow media substrates can significantly enhance the growth and yield of crops in soilless cultures. As soilless cultures offer more possibilities for research, education, and agricultural development, there is an opportunity to address challenges of the green revolution and advocate for a soilless revolution.

References

Adekiya, A.O., Agbede T.M., Aboyeji C.M., Dunsin O. and Ugbe J.O. (2019). Green manures and NPK fertilizer effects on soil properties, growth, yield, mineral and vitamin C composition of okra (*Abelmoschus esculentus* (L.) Moench). *J. Saudi Soc. Agricult. Sci.*, **18(2)**, 218-223.

Ahmed, P., Nath R.K. and Sarma R. (2020). Cultivation of green manuring crops for improving soil health and increasing yield of rice in Tinsukia district of Assam-A case study. *J. Pharmacog. Phytochem.*, **9(2)**, 655-657.

Becker, M., Ladha J.K. and Orrow J.C.G. (1992). Growth and N_2 Fixation of two Stem-Nodulating Legumes and their effect as Green Manure on Lowland Rice. *Soil Biol and Biochem.*, **22**, 1109–1119. DOI: 10.1016/0038-0717(90)90037-Z

Carroll Andrew and Chris Somerville (2009). Cellulosic biofuels. *Annu. Rev. Plant Biol.*, **60**, 165-182.

Carvalho, N.S., Oliveira A.N., CalaÃ M.M., Neto V.P., de Sousa R.S., dos Santos V.M. and de Araujo A.S. (2015) Short-term effect of different green manure on soil chemical and biological properties. *Afr. J. Agricult. Res.*, **10(43)**, 4076-4081.

Cavigelli, M.A. and Thien S.J. (2003). Phosphorus bioavailability following incorporation of green manure crops. *Soil Sci. Soc. America J.*, **67(4)**, 1186-1194. DOI:10.2136/sssaj2003.1186

Chanda, S., Hossain M., Uddin M., Islam M. and Sarwar A.G. (2019). Fiber Yield, Physical and Biochemical Properties of three Species of *Sesbania*. *Bangladesh Agron. J.*, **21**, 79-85.

Chanda, S.C., Rafiqul Islam M. and Golam Sarwar A.K. (2021). Organic Matter Decomposition and Nutrient Release from different Dhaincha (*Sesbania* spp.) Genotypes. *J. Agricult. Sci.* (*Sri Lanka*), **16(2)**.

Chavan, P.D. and Karadge B A. (1986). Growth, mineral nutrition, organic constituents and rate of photosynthesis in *Sesbania grandiflora* L. grown under saline conditions. *Plant and Soil*, **93**, 395-404.

Desa, U. (2022). World Population Prospects 2022: Summary of Results (UN DESA/POP/2022/TR/NO. 3), United Nations Department of Economic and Social Affairs. Population Division, United Nations, New York.

IEhsan, S., Niaz A., Saleem I. and Mehmood K. (2014) Substitution of major nutrient requirement of rice-wheat cropping system through Sesbania green manuring. *Sci. Agric.*, **8**, 99-102.

Elakiya, N. and Arulmozhiselvan K. (2021) Effect of salinity and composition of growing media on growth and Yield of ribbed gourd in soilless culture under matric suction irrigation. *The Pharma Innov. J.*, **10(10)**, 578-585.

Eriksen, J. (2005). Gross sulphur mineralisation–immobilisation turnover in soil amended with plant residues. *Soil Biol. Biochem.*, **37(12)**, 2216-2224. DOI:10.1016/j.soilbio.2005.04.003

Furoc, R.E., Dizon M.A., Morris R.A. and Marqueses E.P. (1985). Effects of flooding regime and planting dates to N accumulation of three Sesbania species and consequently to transplanted rice. Paper presented at the 16th annual scientific convention of the crop science Society of Philippines, 8–10 May 1985, Central Luzon State University Munoz, Nueva Ecija, Philippines, 1985

Fussy, A. and Papenbrock J. (2022). An overview of soil and soilless cultivation techniques—chances, challenges and the neglected question of sustainability. *Plants*, **11(9)**, 1153.

Geethalakshmi, V. (1996). Studies on the Direct and Residual Effect of Non-Conventional Green Leaf Manures with N for Rice-Rice Cropping System. Tamil Nadu Agricultural University, Coimbatore.

Ghai, S.K., Rao D.L. and Lalita B. (1985). Comparative study of the potential of sesbanias for green manuring. *Tropical Agriculture, UK*, **62(1)**, 52-56.

Gruda, N., Caron J., Prasad M. and Maher M.J. (2016). Growing media. In: *Encyclopedia of Soil Sciences*. 3rd Edn., R. Lal., ed. : 2016; 1053–1058. doi: https://doi.org/10.1081/E-ESS3-120053784.

Gruda, N., Savvas D., Colla G. and Rouphael Y. (2018). Impacts of genetic material and current technologies on product quality of selected greenhouse vegetables—A review. *Eur. J. Hortic. Sci.*, **83(11)**, 319-328.

Gu, C., Lv W., Liao X., Brooks M., Li Y., Yu C., Yang L., Li X., Hu W., Dai J. and Zheng W. (2023). Green manure amendment increases soil phosphorus bioavailability and peanut absorption of phosphorus in red soil of South China. *Agronomy*, **13(2)**, 376. https://doi.org/10.3390/agronomy13020376

Gupta, P., Singh J., Verma S., Chandel A.S. and Bhatla R. (2021). Impact of climate change and water quality degradation on food security and agriculture. In : *Water Conservation in the Era of Global Climate Change* 2021; (pp. 1-22). Elsevier.

Hossain, M.A. and Becker K. (2001). Nutritive value and antinutritional factors in different varieties of Sesbania seeds and their morphological fractions. *Food Chem*., **73(4)**, 421-431.

Hu, C., Cao Z.P., Ye Z.N. and Wu W.L. (2006). Impact of soil fertility maintaining practice on soil microbial biomass carbon in low production agro-ecosystem in northern China. *Acta Ecologica Sinica*, **26(3)**, 808-814.

Irin, I.J., Biswas P.K., Ullah M.J., Roy T.S. and Khan M.A. (2019). Influence of green manuring crops on dry matter production and soil health improvement. *Bangladesh Agron. J*., 2019;22(1):39-45.

Irin, I.J. and Biswas P.K. (2023). Residual effect of green manure on soil properties in green manure-transplant aman-mustard cropping pattern. *Indian J. Agricult. Res*., **57(1)**, 67-72. doi: 10.18805/IJARe.AF-696.

Islam, M.M., Urmi T.A., Rana M.S., Alam M.S. and Haque M.M. (2019). Green manuring effects on crop morpho-physiological characters, rice yield and soil properties. *Physiol. Mole. Biol. Plants*, **25**, 303-312.

Kabir, A.K., Moniruzzaman M., Gulshan Z., Rahman A.B. and Sarwar A.K. (2018). Biomass Yield, Chemical Composition and *in vitro* Gas Production of different Dhaincha (*Sesbania* spp.) Accessions from Bangladesh. *Indian J. Anim. Nutr*., **35(4)**, 397-402.

Kameswari, P.L., Girwani A. and Padmavathamma A.S. (2014). Effect of different potting media mixtures on growth and flowering of chrysanthemum (*Dendranthema grandiflora* T.). *Progressive Horticulture*, **46(2)**, 314-318.

Karagöz, F.P., Dursun A. and Karaşal M. (2022). A review: use of soilless culture techniques in ornamental plants. *Ornamental Horticulture*, **28**, 172-180.

Kautz, T., Wirth S. and Ellmer F. (2004). Microbial activity in a sandy arable soil is governed by the fertilization regime. *Europ. J. Soil Biol*., **40(2)**, 87-94. DOI:101016/jejsobi200410001

Kumar, R., Mahajan G., Srivastava S. and Sinha A. (2014). Green manuring: a boon for sustainable agriculture and pest management–a review. *Agricultural Reviews*, **35(3)**, 196-206. DOI: 105958/0976-07412014009064

Ladha, J.K., Watanabe I. and Saono S. (1988). Nitrogen fixation by leguminous green manure and practices for its enhancement in tropical lowland rice. In: The International Rice Research Institute (ed) Sustainable agriculture: green manure in rice farming. IRRI, Los Banos, 1988; pp 165–183

Lee, C.R., Kim S.H., Oh Y., Kim Y.J. and Lee S.M. (2023). Effect of Green Manure on Water-Stable Soil Aggregates and Carbon Storage in Paddy Soil. *Korean J. Soil Sci. Fertilizer*, **56(2)**, 191-198.

Liu, G.S., Luo Z.B., Wang Y., Li H.L., Wang G.F. and Ma J.M. (2006). Effect of green manure application on soil properties and soil microbial biomass in tobacco field. J. *Soil Water Conser.*, **20**, 95 – 98.

MacRae, R.J. and Mehuys G.R. (1985). The effect of green manuring on the physical properties of temperate area soils. *Adv Soil Sci.*, **3**, 71–94. DOI: 101007/978-1-4612-5090-6_2

Maitra, S., Zaman A., Mandal T.K. and Palai J.B. (2018). Green manures in agriculture: A review. *J. Pharmacog. Phytochem*., **7(5)**, 1319-1327.

Mandal, U.K., Singh G., Victor U.S. and Sharma K.L. (2003). Green manuring: its effect on soil properties and crop growth under rice–wheat cropping system. *Europ. J. Agron*., **19(2)**, 225-237.

Mann, R.A., Zia M.S. and Saleem M. (2000). An improved green manure technology for sustaining the wheat rice system. *Quart. Sci. Vision*, **6(2)**, 53.

McGinnis, M.S., Bilderback T.E. and Warren S.L. (2009). Vermicompost Amended pine bark provides most plant nutrients for *Hibiscus moscheutos'luna* Blush'. In : *International Symposium on Growing Media and Composting*, **891**, 249-256.

Meelu, O.P., Furoc R.E., Dizon M.A., Morris R.A. and Marqueses F.P. (1985). Evaluation of different green manures on rice yield and soil fertility. Paper presented at the *16th annual scientific convention of the Crop Society of Philippines*, 8–10 May, 1985, Central Luzon State University, Munoz, Nueva Ecija, Philippines.

Meena, B.L., Fagodiya R.K., Prajapat K., Dotaniya M.L., Kaledhonkar M.J., Sharma P.C., Meena R.S., Mitran T. and Kumar S. (2018). Legume green manuring: an option for soil sustainability. *Legumes for soil health and sustainable management*, **2018**, 387-408.

Morris, R.A., Furoc R.E. and Dizon M.A. (1986). Rice Responses to a Short duration Green Manure. II. N Recovery and Utilization 1. *Agron. J*., **78(3)**, 413-416.

Munawar, A. and Suhartoyo H. (2013). Litter production and decomposition rate in the reclaimed mined land under albizia and sesbania stands and their effects on some soil chemical properties. *J. Tropical Soils*, **16(1)**, 1-6.

Noor-A-Jannat, S. Ahmed, Abuyusuf M., Hassan M.Z., Lipi N.J. and Biswas K.K. (2015). Nitrogen fertilizer after green manuring on the yield of *T. aman* rice. *Amer. Res. Thoughts*, **1**, 2898-2909.

Oehl, F., Oberson A., Probst M., Fliessbach A., Roth H.R. and Frossard E. (2001). Kinetics of microbial phosphorus uptake in cultivated soils. *Biology and Fertility of Soils*, **34**, 31-41. DOI: 101007/s003740100362

Phiri, E., Verplancke H., Kwesiga F. and Mafongoya P. (2003). Water balance and maize yield following improved sesbania fallow in eastern Zambia. *Agroforestry Systems*, **59**, 197-205.

Rahman, M.H., Islam M.R., Jahiruddin M., Rafii M.Y., Hanafi

M.M. and Malek M.A. (2013). Integrated nutrient management in maize-legume-rice cropping pattern and its impact on soil fertility. *J. Food Agric. Environ.*, **11(2)**, 648-652.

Rani, T.S., Ramulu C., Kumar T.S. and Rao P.J. (2020). Evaluation of Dhaincha (*Sesbania aculeata* L.) accessions for greetn manuring traits and soil fertility improvement. *J. Pharmacog. Phytochem.*, **9(6)**, 1932-1936.

Rumball, W. (1986). Grasslands Puna'chicory (*Cichorium intybus* L.). *N Zeal. J. Exp. Agricult.*, **14(1)**, 105-107.

Sarwar, A.K., Hossain S.Z. and Chanda S.C. (2017). Effect of Dhaincha accessions on soil health and grain yield of rice. *J. Biosci. Agricult. Res.*, **13(02)**, 1140-1145.

Sarwar, A.K. (2015). Characterization of dhaincha accessions based on morphological descriptors and biomass production. *J. Bangl. Agricult. Univ.*, **13(1)**, 49-54.

Sas, L., Rengel Z. and Tang C. (2001). Excess cation uptake, and extrusion of protons and organic acid anions by Lupinus albus under phosphorus deficiency. *Plant Science*, **160(6)**, 1191-1198. DOI:101016/S0168-9452(01)00373-9

Schmilewski, G. (2007). Growing medium constituents used in the EU. In : *International Symposium on Growing Media*, **819**, 33-46.

Schwarz, D., Franken P., Krumbein A., Kläring H. and Bar-Yosef B. (2009). Nutrient management in soilless culture in the conflict of plant, microorganism, consumer and environmental demands. *Acta Hort.*, **843**, 27-34.

Selvi, R.V., Nadanassababady T. and Rajendran P. (2005). Green manuring in lowland rice–A review. *Agricult. Rev.*, **26(1)**, 14-26.

Sharpley, A.N. and Smith S.J. (1989). Mineralization and leaching of phosphorus from soil incubated with surface applied and incorporated crop residue. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America. DOI: 10.2134/jeq19890047242500180001 0018x

Shen, J., Li H., Neumann G. and Zhang F. (2005). Excess cation uptake, and extrusion of protons and organic acid anions by *Lupinus albus* under phosphorus deficiency. *Plant Science*, **168**, 837-845. DOI: 101016/S0168-9452(01)00373-9

Shi, J. (2013). Decomposition and nutrient release of different cover crops in organic farm systems.

Singh, Y., Khind C.S. and Singh B. (1991). Efficient management of leguminous green manures in wetland rice. *Adv. Agron.*, **45**, 135-189.

Sutar, R., Sujith G.M. and Devakumar N. (2019). Growth and yield of cowpea [*Vigna unguiculata* (L.) Walp] as influenced by jeevamrutha and panchagavya application. *Leg. Res.-An Int. J.*, **42(6)**, 824-828.

Swarup, A. (1991). Effect of Sesbania bispinosa decomposition time and sodality on rice yield. *AGRIS Agricult. Inform. Manage. Standards*, **13**, 28-29.

Talgre, L., Lauringson E., Roostalu H., Astover A. and Makke A. (2012). Green manure as a nutrient source for succeeding crops.

Thonnissen, C., Midmore D.J., Ladha J.K., Olk D.C. and Schmidhalter U. (2000). Legume decomposition and nitrogen release when applied as green manures to tropical vegetable production systems. *Agron. J.*, **92(2)**, 253-260.

Thorup-Kristensen, K., Magid J. and Jensen L.S. (2003). Catch crops and green manures as biological tools in nitrogen management in temperate zones.

Tissen, H., Cuevas E. and Chacon P. (1994). The role of organic matter in sustaining soil fertility. *Nature*, **371**, 783–785.

Tzortzakis, N., Nicola S., Savvas D. and Voogt W. (2020). Soilless cultivation through an intensive crop production scheme. Management strategies, challenges and future directions. *Front. Plant Sci.*, **11**, 529970. https://doi.org/10.3389/fpls.2020.00363

Unicef (2018). The state of food security and nutrition in the world 2018: building climate resilience for food security and nutrition. FAO; 2018.

Velazquez-Gonzalez, R.S., Garcia-Garcia A.L., Ventura-Zapata E., Barceinas-Sanchez J.D. and Sosa-Savedra J.C. (2022). A review on hydroponics and the technologies associated for medium-and small-scale operations. *Agriculture*, **12(5)**, 646. https://doi.org/10.3390/agriculture12050646

Watanabe, I. (1984). Use of green manure in northeast Asia. In: International Rice Research Institute (ed) Organic matter and rice. IRRI, Los Banos, pp 229–234.

Xie, Z., Tu S., Shah F., Xu C., Chen J., Han D., Liu G., Li H., Muhammad I. and Cao W. (2016). Substitution of fertilizer-N by green manure improves the sustainability of yield in double-rice cropping system in south China. *Field Crops Res.*, **188**, 142-149.

Yang, L., Bai J., Liu J., Zeng N. and Cao W. (2018). Green Manuring effect on changes of Soil Nitrogen Fractions, Maize Growth and Nutrient uptake. *Agronomy*, **8(11)**, 261. https://doi.org/10.3390/agronomy8110261

Ye, X., Liu H., Li Z., Wang Y., Wang Y., Wang H. and Liu G. (2014). Effects of green manure continuous application on soil microbial biomass and enzyme activity. *J. Plant Nutr.*, **37(4)**, 498-508.