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Effect of Organic and Inorganic Nutrient Sources on Productivity, Grain Quality of Rice and Soil Health in North-West IGP: A Review

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Nutrient supply is the most limiting factor next to the water for crop production. Sustaining rice production has become a great challenge, particularly in areas where rice productivity declines in spite of following recommended nutrient management practices. Nutrient management by integrating organic sources of nutrients along with inorganic fertilizers may play an important role in improving and sustaining rice productivity moreover, chemical fertilizers will play a major role as these contribute about 50% to the increase in food grain production for ever increasing population of our country. Successful nutrient management can optimize crop yields, increase profitability and minimizes nutrient losses. Organic fertilizer improves physical and biological activities of soil but they have comparatively low in nutrient content, so larger quantity is required for plant growth. However, inorganic fertilizer is usually immediately and fast containing all necessary nutrients that are directly accessible for plants. But continuous use of inorganic fertilizers alone causes soil organic matter: degradation, soil acidity and environmental pollution. So the integrated nutrient management system is an alternative system for the sustainable and cost-effective management of soil fertility by combined apply of inorganic with organic materials resulting in rising soil fertility and productivity without affecting environment. Treatment T_6 increased the net photosynthesis rate, total biomass, grain yield, and amylose content by 23%, 90%, 95%, and 10%, respectively, compared with control. This increment in growth was the result of 14%, 19%, and 20% higher total root length, root surface area, root volume, and root diameter, respectively. Improvements in these attributes further enhanced the grain yield and nitrogen use efficiency of rice.The application of organic manure alone or along with bio-fertilizers inoculation significantly improved the N, P, K and S uptake by rice over control. However maximum improvement in soil health related to available nutrient status, soil microorganism population was observed in organic nitrogen sources alone or along with bio-fertilizers. The 50% organic fertilizer and 50% CF led to increased NPK availability and rice yields over the 100% CF treatment, reducing CF usage and leading for sustainable agriculture. This review provides a sustainable nutrient management strategy to improve crop yield with high nutrient use efficiency.

Introduction

Rice is staple food crop of Asian population and in India, area, production and productivity of rice is 43.79 mha, 112.91 mt and 2.57 t/ha, respectively (Anonymous, 2018). Nutrient supply is the most limiting factor next to the water for crop production. Sustaining rice production has become a great challenge, particularly in areas where rice productivity declines in spite of following recommended nutrient management practices. Nutrient management by integrating organic sources of nutrients along with inorganic fertilizers may play an important role in improving and sustaining rice productivity (Mondal *et al.*, 2016), moreover, chemical fertilizers will play a major role as these contribute about 50% to the increase in food grain production for ever increasing population of our country (Mahajan and Gupta, 2009). Successful nutrient management can optimize crop yields, increase profitability and minimizes nutrient losses. With the progress of science when we think about Green-energy, sustainability, and environmental safety, we should have a look on modern tools to integrate nutrient management. The decline in the rice crop responses to applied fertilizer nutrients, inter alia, could be ascribed to emerging nutrient deficiencies on account of modern era of agriculture and inadequate or imbalanced application of fertilizers. It has become increasingly recognized around the world that N, P and K fertilizers alone are not always sufficient to provide balanced nutrition for optimal rice yields and quality, therefore, application of secondary and micronutrient elements has to be made. Comparing western U.P. and Punjab in the north and Tamil Nadu in the south, the N: P_2O_5: K_2O consumption ratio is much wider in western U.P. and Punjab (42.6:11.9:1.0) as compared to Tamil Nadu (2.6:1.0:1.0). This indicates that the highest fertilizer consuming states have the greatest imbalanced use of nutrients. The main reason of the variation in fertilizer consumption ratios in north and south is due to the nature of soils and cropping pattern. About 35% of total fertilizer is consumed by rice in India (Datta *et al.*, 2010).

Cultivation of high yielding dwarf varieties responsive to fertilizer and irrigation in intensive cropping after green revolution with continuous and excess use of inorganic fertilizers has depleted the inherent soil fertility. The decline or stagnation in yield has been attributed to nutrient mining and reduced use of organics (John *et al.*, 2001). Several long-term experiments all over India indicated a decrease in rice productivity due to continuous use of chemical fertilizers. Integrated nutrient management (INM) aims to improve soil health and sustain high level of productivity and production (Prasad *et al.*, 1995). Farmyard manure (FYM) is being used as major source of organic manure in field crops as it supplies all essential plant nutrients and increases activities of microbes in soil (Sutaliya and Singh, 2005). Limited availability of FYM is however an important constraint in its uses as source of nutrients. Sharma (2002) reported increased yield and nutrient use efficiency in rice with organics. Organics supply nutrients at the peak period of absorption, and also provide micro nutrients and modify soil- physical behaviour as well as increase the efficiency of applied nutrients (Pandey *et al.*, 2007). It is widely recognized that neither use of organic manures alone nor chemical fertilizers can achieve the sustainability of the yield under the modern intensive farming. Contrary to detrimental effects of inorganic fertilizers, organic manures are available indigenously which improve soil health resulting in enhanced crop yield. However, the use of organic manures alone might not meet the plant requirement due to presence of relatively low levels of nutrients. Therefore, in order to make the soil well supplied with all the plant nutrients in the readily available form and to maintain good soil health, it is necessary to use organic manures in conjunction with inorganic fertilizers to obtain optimum yields (Ramalakshmi *et al.,* 2012).

Nitrogen is the most important nutrient and varying organic and inorganic nitrogen sources have significant effect and crucial role on quality of rice grain. Integrated nutrient management including biofertilizers, organics and chemical fertilizers may improve productivity and the quality of rice grain. Biofertilizers alone or in combinations with organic manures improve the quality parameters of scented rice (Dixit and Gupta, 2000; Quyen and Sharma, 2003). Head rice recovery and alkali value of scented rice varieties improved due to application of farmyard manure (Pandey *et al.,* 1999). Lower doses of organic manures improved the quality parameters like hulling, milling and head rice recovery than higher doses (Saha *et al.,* 2007). Milling, head rice recovery, kernel length and length: breadth ratio after cooking of rice significantly improved when organic manures applied in combination with inorganic (Pandey *et al.,* 1999; Quyen and Sharma, 2003; Shrivastava *et al.*, 2009).

Effect of integrated nutrient management on rice yield attributes and yield

Yadav *et al.,* (2005) further reported that rice yield was maximum with 25% N substitution through green leaf manure +100% NPK fertilizer in rice-wheat cropping system. Mehedi *et al.,* (2011) further conclude that sesbania at 20tha^{-1} + 75% recommended dose of chemical fertilizer proved to be the best combination to get reasonable yield. Greater tiller number, filled grains per panicles , 1000-grain weight and an optimum yield of rice was obtained by application of 120: 60: 45 kg N: P_2O_5:K_2O ha^{-1} in combination with farm yard manure than the individual sources of NPK and control (Satyanarayana *et al.,* 2002). Virdia and Mehta (2008) reported that application of press-mud @ 20 t/ha along with recommended dose of fertilizer gave the highest grain yield which was on par with press-mud @ 15 t/ha + RDF in 2000 and 2005 and with or FYM @ 10 t/ha + RDF in 1995 (Table 1). This might be due to improvement in nutrient supply with more organics, which improves soil physic-chemical and biological properties by providing essential food to microbes (Sutaliya and Singh, 2005). The liquid organic manures contains small amount of nutrients and growth boosters. When it applied to the crops it removes the imbalances in terms of physical, chemical and physiological aspects and harmonizes the basic element which revitalizes the growth process (Natarajan, 2008). Application of soil + mine spoil + coir pith vermicompost (1:1:1)+ RDF significantly enhanced plant height (27.2 cm), number of leaves (33.3), and yield per plant (38.5g), as compared to mine spoil alone + RDF. Somasundaram *et al.* (2003) application of panchagavya @ 3% significantly increased grain yield (17.7 q/ha), number of seed per pod (12.1) and 100 grain weight (4.0g) as compared to application of recommended dose of fertilizer. The result revealed that the yield components viz., productive tillers/hill, panicle length, filled grain panicle, seed test weight, grain yield and straw yield were found significantly higher in the treatment of panchgavya spray @ 3% Yadav and Christophe (2006).

Application of 33t FYM 8t neem cake/ha significantly increases the grain yield (20.5 q/ha) and straw yield (24.5 q/ha) of soybean. Whereas, the highest crude protein (19.3%) observed in the treatment received the nutrients based on STCR target 25 q/ha (50145:43 NPK kg/ha) Patil *et al.,* (2008). Kagne *et al.,* (2008) observed that application of vermicompost @ 2.5 t/ha along with seed treatment of Azospirillum and PSB enhanced the growth and quality of sorghum and produced highest seed yield (21.7 q/ha). application of 50% RDN + 50% N through FYM, VAM and PSB @ 12.5 kg/ha + panchagavya @ 3% spray recorded significantly higher number of branches/plant, number of fruits/plant, fruit length and fruit yield as compared to RDF. Kumar and Haefele (2013) reported that application of nitrogen at 90 kg level as 50% through Rice straw compost + 50% nitrogen as poultry manure registered higher growth, grain and straw yield. However, with regard to N management, LCC 4 and 5 based On N applications recorded higher grain yield as a result of higher soil available nutrients during the critical growth stages. Venkatalakshmi *et al.,* (2009) observed that foliar application of panchagavya @ 3 % significantly increased number of leaves, LAI, green leaf yield and dry matte yield of *Amaranthus viride* and also higher result indicated that when panchagavya applied @ 3% and 6% with seed soaking treatment recorded 11 and 9 t/ha green leaf yield. Application of FYM @ 6 t/ha + Rhizobium + PSM significantly increased plant height (32.9 cm), pod weight per plant (11.9), seed index (55.3 g) and yield (1278 kg/ha) Zalate and Padmani (2009).

Sharma (2013) revealed that the growth, development, yield attributes of rice was found to be best when 50% N through farm yard manure and 50% NPK was applied in rice-wheat cropping system. Moreover Ali *et al.,* (2009) reported that significantly highest grain and straw yield of rice (5.52 t ha^{-1} and 6.73 t ha^{-1} respectively) was obtained in 70% of recommended dose of chemical fertilizers and 3 tones poultry manure ha^{-1} than 70% NPKS alone and the control. Moreover Khan *et al.,* (2007) observed the combined fertilizer application of NPK: GM: Zn (soil application) at a rate of 120-90-60 kg ha^{-1}: 10 t ha^{-1}: 10kg ha^{-1} gave significantly maximum plant height, number of tillers, number of panicles, number of spikelet's, 1000 grain weight, yield and straw yield of paddy rice as compared to NPK alone and the control (Table 2). Ranjitha *et al.,* (2013) observed that significantly maximum grain and straw yield of rice was recorded with the application of 50 %recommended dose of nitrogen through urea + 50 % recommended dose of nitrogen through vermicompost. It was also noticed that straw yield of rice was 3.7, 15.9 and 20.7 % higher when NPK applied with farm yard manure, vermicompost and poultry manure, respectively as compared to NPK alone (Khursheed *et al.,* 2013). Larijani and Hoseini (2012) also found that more tiller number (28%), more panicle/m^2 (60%), number of filled grains/m^2 (20.6%), spikelet per panicle (19.6%) and more grain yield (30.6%) with combined use of organic and chemical fertilizer compared with chemical fertilizer alone

Mahmud *et al.,* (2016) showed that application of medium level of chemical fertilizer with 4 t ha^{-1} vermi-compost gave the maximum yield. It was observed that over dose of NPKS fertilizers from chemical source decreased rice yield. Results also revealed that the highest plant height, effective tillers hill^{-1}, flag leaf length, panicle length, filled grains panicle^{-1}, 1000-grain weight, grain yield, straw yield and biological yield were obtained from the combination of 4 t ha^{-1} vermi-compost with 100 kg ha^{-1} N, 16 kgha^{-1} P,66 kgha^{-1} K, 12 kgha^{-1}S.It was observed that yield of rice can be increased substantially with the judicious application of organic fertilizer with chemical fertilizer. Sharada and Sujathamma, (2018) revealed that the variety DRR Dhan 39 gave the statistically significant higher grain and straw yield with 50% organic fertilizers of Vermicompost, Jeevamrutha 5% and Panchagavya 3% and 50% inorganic fertilizer of NPK. Chinnamani *et al.,* (2018) also found that under system of rice intensification combined application of 100 % RDF + poultry manure (3 t ha^{-1}) + 3% Panchakavya foliar spray at transplanting, panicle initiation and 50% flowering observed the best integrated nutrient management practice for higher yield and nutrient uptake.

Kumar *et al.,* (2014) observed that the application of organic and inorganic source of nutrient in combination increased the yield attributes (Table 3). Application of 125% RDF + 5 t/ha vermin-compost recorded significantly higher yield attributes viz. number of panicle/m^2, panicle length , panicle and test weight followed by treatment 100% RDF + 5 t/ha vermin-compost. Moreover, other treatments were significantly superior over control. Similar finding were also reported by Ramalakshmi *et al.,* (2012); Alim (2012). The higher yield attributes is might be due to higher levels of inorganic fertilizers have been increases the activity of photosynthesis and enzymes which responsible for transformation of energy, carbohydrates, fat metabolism and respiration of plant. Organic manures acting as slow release source of N are expected to more closely match with N and supply of other nutrients with demand of rice crop and this could reduce the N losses and also improved the nutrient use efficiency particularly of nitrogen (Becker *et al.,* 1994). Saba *et al.,* (2013) further noticed that combination of bio-fertilizer, nitrogen and phosphorous (500: 120: 90 kg ha^{-1}) exceeded all other treatments including P and N alone in number of tillers m^{-2}, number of panicles m^{-2}, number of spikelet's panicles^{-1}, percent normal kernels, 1000-grain weight (g) and paddy yield (t ha^{-1}).

Baishya *et al.,* (2015) reported that the different sources of organic manure and inorganic fertilizers influenced positively the growth and yield of paddy (Table 4). Among the nutrient management practices, crop receiving 2.5 t poultry manure ha^{-1} + 125% CDF (75 + 16.5 + 31.3 kg N P and K ha^{-1}) recorded the taller plants, higher effective tillers, panicle length, grain and straw yield which closely followed by the 2.5 t poultry manure ha^{-1} + 100% CDF (60 +13.1 + 25 kg N, P and K ha^{-1} and 5t FYM ha^{-1} along with 125% CDF (75 + 16.5+ 31.3 kg N P and K ha^{-1}. However, among the organic sources, addition of vermin-compost (1tha^{-1}) produced better growth and grain yield followed by 2.5 t poultry manures ha^{-1} and 5t FYM ha^{-1}. This might be due to better and timely nutrient availability to the crop from the vermin-compost as compared to other sources of organic manure. This is in conformity with the findings of Singh and Kumar (2014). Application of 100 % recommended dose of nitrogen from urea significantly influenced the yield of rice in 1st year of experiment but during the 2nd year of experiment application of 50 % recommended dose of nitrogen from vermicompost and the rest through chemical fertilizer (urea) produced significantly highest grain and straw yield of rice in rice-wheat cropping system (Koushal *et al.,* 2011). Moreover, the mean grain yield of rice for the three years showed that significantly higher rice yields than the other treatments at 4.0 t ha^{-1} PM + 30 kg Nha^{-1} and 2.0 t ha^{-1} PM + 22.5-15-15 kg N: P_2O_5: K_2O ha^{-1} (Issaka *et al.,* 2014). Larijani and Hoseini (2012) also found that more tiller number (28%), more panicle/m^2 (60%), number of filled grains/m^2 (20.6%), spikelet per panicle (19.6%) and more grain yield (30.6%) with combined use of organic and chemical fertilizer compared with chemical fertilizer alone.

Moe *et al.,* (2019) reported that higher tiller numbers were observed in the $CF_{50}PM_{50}$ treatment across all growth stages. The maximum tiller number was observed at 40 DAT; 34.73 and 38.22 tillers per hill in the $CF_{50}PM_{50}$ plots in 2017 and 2018, respectively (Fig. 1a). Tiller numbers declined after 45 DAT in all treatments. At harvest time, the maximum tiller numbers of 18.2 and 22.5

tillers per hill were observed in $CF_{50}PM_{50}$ plots in 2017 and 2018, respectively. The development of the tiller primordium depends on the N, P, and K contents in leaves and sheaths. Tiller number increases linearly with sheath N content (Yoshida, 1981). A high sheath N content increases the cytokinin content within tiller nodes and enhances the germination of the tiller primordium (Liu *et al.,* 2011). Similarly rice plants accumulated a large amount of DM during the tillering stage in the CF100 treatment in 2017 (Fig. 1b). After that stage, DM production was similar among the CF_{100}, $CF_{50}PM_{50}$, $CF_{50}CM_{50}$, and $CF_{50}CP_{50}$ treatments. At harvest, the maximum DM produced was 15.01 t ha^{-1}, from the $CF_{50}PM_{50}$treatment, followed by 14.29 t ha^{-1} in the CF_{100} treatment. The amounts of DM produced in the $CF_{50}CM_{50}$ and $CF_{50}CP_{50}$ treatments were 12.30 and 11.26 t ha^{-1}, respectively. The most DM was produced in $CF_{50}PM_{50}$ plots in 2018 even during the early stage. Throughout the crop period, plots treated with organic fertilizers produced DM amounts similar to those from plots treated with CF_{100}. At harvest time, $CF_{50}PM_{50}$ plots produced the most DM, 15.49 t ha^{-1}. $CF_{50}CM_{50}$and $CF_{50}CP_{50}$ also produced significantly more DM in 2017 than in 2018. DM production in the $CF_{50}CM_{50}$and $CF_{50}CP_{50}$ treatments was not significantly different from that in the CF_{100} treatment. Plants treated with CF100 produced more DM than plants treated with organic fertilizers. The CF used is readily soluble and hence can supply nutrients to rice plants within a short time after application (Sarker *et al.,* 2017).

Kumar *et al.*, (2017) revealed that combined application of FYM + BGA produced significantly higher growth parameters, yield attributes and yield of rice over FYM and control (Table 5). Hence, aromatic rice can be grown with 100% RDF and FYM along with BGA for higher growth and productivity under eastern U. P condition. Devkota *et al.*, (2019) showed that application of half of recommended N: P_2O_5: K_2O from the inorganic fertilizer sources along with soil incorporation of 20 cm crop residue produced significantly higher value for plant height, number of tillers per square meter, panicle length and Grain yield.

Tiwari *et al.,* (2017) observed that the application of 50% RDF+ 50% nutrient through FYM recorded highest growth parameter and yield in rice (Table 6). The higher growth and yield of rice may be attributed to good soil health due to the application of farm yard manure with fertilizes; many other scientists have also observed the same phenomenon.

Baghdadi *et al.,* (2018) revealed that the combining chemical fertilizers with chicken manure (CM) in a 50:50 ratio and applying 50% NPK+50% CM+BF produced grain and dry matter (DM) yields that were similar to those produced in the 100% nitrogen (N), phosphorus (P), potassium (K) treatment. Among the lone fertilizer treatments, the inorganic fertilizer (100% NPK) treatment produced the highest DM yield and out yielded the 100% CM treatment. However, when CM was combined with NPK, the resulting DM yield was the same as that resulting from 100% NPK (13.68 t/ha). Compared with CM applications alone, combinations of NPK and CM applications resulted in increased plant height, crop growth rates (CGRs) and leaf area index (LAI), but the values of these parameters were similar to those resulting from 100% NPK application.

Iqbal *et al.,* (2019) also found that biomass and N accumulation increased progressively with improved growth and attained the highest weight at maturity. Biomass and N accumulation (NA) differed significantly between control and N embedded treatment (Fig. 2A–D). The differences among treatments showed a similar trend for both seasons. Sole urea application (T_2) resulted in a higher biomass (18.14 g $hill^{-1}$ and NA 0.38 g $hill^{-1}$) at the tillering stage across the seasons, while at heading and maturity, there was maximum biomass accumulation (43.32 and 66.22 g $hill^{-1}$) and NA (0.43 and 0.67.56 g $hill^{-1}$), respectively, in T_6 across the seasons. In-addition, T_2 and T_4 were statistically comparable with T_6. The lowest biomass and NA were observed in control, followed by T_5 and T_3, during both seasons. Co-applied organic and inorganic fertilizer had significantly increased nitrogen use efficiency (NUE) compared with sole inorganic fertilizer application. Among the treatments, T_6 showed higher NUE by 43.5%, followed by T4at 42.8%, across the seasons (Fig. 2E–F). Similarly, T_3 and T_5 also increased the NUE, and lower NUE was noted in sole urea fertilizer treatment during both seasons. Moe *et al.,* (2017) observed that there was no statistically significant difference in the number of tillers generated using I_{100} compared with 50% NPK (I_{50}) inorganic fertilizer. However, a larger number of tillers were present in rice plants grown using I_{100} compared with 0% NPK (I_0) fertilizer. The maximum tiller number was produced using I_{75}Op in the dry season (19.22 $hill^{-1}$) and I_{100}Op in the wet season (17.00 $hill^{-1}$) [Fig.2b].

Singh *et al.,* (2018) stated that the grain and straw yield and harvest index of rice increased with the application of 100 % RDF and more increased when 25 or 50 % nutrients substituted through organic sources i.e. FYM, GM or wheat straw along with 75 or 50 % RDF. The maximum rice grain and straw yield and harvest index were obtained with 50 % RDF+50 % N as FYM (Table 7) which remained at par with treatments, 50%RDF+50% N as wheat straw and 50%RDF+50%N as GM. The higher yield was achieved through integrated nutrient management because the grain and straw yield is the final product which depends upon the development of yield components such as effective tillers, panicle length, test weight, total and filled grain $panicle^{-1}$. All the yield attributes and yield were higher with the substitution either 25 or 50 % N as FYM or green manure or wheat straw in combination with 50 or 75% RDF due slow release and continuous supply of nutrients in balance quantity throughout the various growth stages enables the rice plants to assimilate sufficient photosynthetic products and thus, increased the dry matter and source capacity resulted in increased of yield attributes and finally yield of grain and straw. Furthermore, substitution of 25 or 50 organic in combination with 50-75% RDF improved physicochemical and biological properties of soil which improved the efficiency in utilization of native as well as applied nutrients at faster rate, which favoured better plant growth and improved the yield components of rice (Pandey *et al.,* 2007). Thus, the application of 50 % RDF along with 50 % N either through FYM or green manure or wheat straw may be recommended for getting higher grain yield of rice.

Gangmei and George (2017) observed that the significant and highest grain yield was reported in treatment T_{11}, however treatments T_{10}, T_9 and T_8 shows parity with T_{11}. There was 59.47 % increase in grain yield ha^{-1} in T_{11} over T_{12}. Also addition of 10 tonnes FYM with 100 RDF (T_{11}) increases the grain yield by 29.57 % over 100 RDF (T_5) alone. Further, highest straw yield was reported in treatment T_{11} which is at par with T_{10}, T_8, T_9 and T_7. The lowest straw yield (kg ha^{-1}) was observed in T_{12} (No manure and fertilizer) which is also at par with T_1, T_2 and T_3. The maximum yield attained in treatments where integrated use of FYM and inorganic fertilizers were due to the fact that inorganic fertilizers releases nutrients for the plants instantly and in readily available forms for the plants during its growth, development and reproductive phases where the nutrient demand is at its peak. Micro nutrients supplied by the FYM enhanced the macro nutrients uptake and also slowly release during the whole crop period. Slow-acting bulky organic manures like compost and farm yard manure are hard to decompose (because of wider C: N ratio) and making nitrogen available at later stages (Khan *et al.,* 2001). Organic fertilizer with inorganic fertilizer increased the fertilizer use efficiency and improved the physical and chemical properties of soil and it would be a reason towards increased yield (Banik *et al.*, 2006). Increasing the levels of nutrients enhances the nutrient availability thereby increases yield attributes such as number of effective tillers hill-1 number of spikelet's panicle-1, percentage of filled grains and test weight.

Effect of integrated nutrient management on soil health

Why integrated soil fertility management?

Sustaining soil fertility and increasing productivity using organic resources alone would be required large amount of organic fertilizer to maintain soil fertility levels in each and every field. However, the opposite strategy, the use of inorganic fertilizers alone may lead to high crop yields in the short period of time. But it affects soil structure which leads to decline of organic matter and environmental pollution (Ali *et al.,* 2009). The problems associated with the single approach application of organic or inorganic fertilizers have made a combination of organic and inorganic fertilizers a realistic option in improving soil fertility and productivity. So the best ways for soil fertility is, therefore, integration of both inorganic and organic fertilizers to increases soil productivity as well as soil fertility (Nyalemegbe *et al.,* 2009) by less expensive ways (Nyalemegbe *et al.,* 2009; Mungai *et al.,* 2009) and decreases the damage that can be induced by chemical fertilizers (Han *et al.,* 2016). Brar *et al.,* (2015) showed that integrated use of inorganic fertilizer along with organic fertilizer (100% NPK + FYM) improved soil physical conditions such as CEC and pH resulted in higher yields. According to Han *et al.,* (2016) the NPK fertilizer treatment leads to soil acidification, whereas organic manure + NPK treatments significantly increased soil pH. Similar type findings was reported by (Walia *et al.,* 2010) also found that the incorporated nutrient management system results in rising organic carbon content, available nitrogen, phosphorus and potassium increasing from 0.390% to 0.543%, 171.7 to 219.3 kgha^{-1} and 20.5 to 43.3 kgha^{-1} respectively.

Tharmaraj *et al.,* (2011) reported that soil application of vermicompost and spray of vermiwash improved physical (water holding capacity, porosity and moisture content), chemical properties (pH and EC) as well as soil fertility (N, P, K, Ca and Mg over control and its individual application. Effect of integrated nutrient management on soil fertility management on soil fertility were studied by Naidu et al. (2009) and results revealed that highest status of major and micronutrients in soil in the treatment, 50% RDN+50% N through FYM + BF + Panchagavya @ 3% foliar spray similar results were obtained by Ansari and Kumar (2010) i.e. The significantly higher content of organic C in the treatment of vermiwash +vermicompost followed by only vermicompost and only cowdung (100 g/plant). However, higher content of N, P, K, Ca, Mg, Fe, Mn, Zn and Cu were observed in the chemical fertilizer treatment followed by treatments of vermiwash + vermicompost

Dubey *et al.,* (2014) reported that the improvement in organic carbon and nitrogen contents as well as maintenance of phosphorus and potash contents was noticed over their initial status under 100% organic nutrient management with all cropping systems till the completion of fourth crop cycle. The organic carbon and nitrogen content were almost maintained and phosphorus and potash contents showed a little declining trend over their initial status with 100 % inorganic nutrient management. Baishya *et al.,* (2015) concluded that the crop receiving 2.5 t poultry manure ha^{-1} along with 75 kg N +16.5 kgP+31.3 kg K ha^{-1} recorded significant improvement (Table 8) in soil organic carbon, nitrogen, phosphorus and potassium status of soil after harvest of the crop. Kumar and Haefele (2013) reported that application of nitrogen at 90 kg level as 50% through Rice straw compost + 50% nitrogen as poultry manure registered higher available N, P and K contents of soil during different growth stages as compared to the other treatment combinations. Naresh *et al.,* (2015) reported that SOC concentration in surface soil (0– 15 cm) was not significantly or slightly increased by the 15 yr of fertilizer treatments (N), but they were sharply increased by the manure and straw amendment (FYM, and FYM+GM/SPM). Thus, returning crop residue to the soil or adding farmyard manure on the soil surface is crucial to improving the SOC level. The large scale implementation of the straw or manure plus inorganic fertilizer amendments will help to enhance the capacity of carbon sequestration and promote food security in the region.

Mallikarjun and Maity (2018) reported that the highest bacterial count (39.4 X 10^5 CFU g^{-1} and 40.5 X 10^5 CFU g^{-1}, fungal population (14.06 X 10^3 CFU g^{-1} and 15.08 X 10^3 CFU g^{-1},actinomycetes population (30.2 X 10^2 CFU g^{-1} and 32.8 X 10^2 CFU g^{-1} in the year 2015 and 2016, respectively) was observed with the application of 50% N as chemical fertilizer with 25% FYM along with Azollain a dual cropping, were statistically at par with the application of 75% N as chemical fertilizer along with Azolla. However, the application of organics along with chemical fertilizers registered a significant increase in bacterial, fungal and actinomycetes population over control. Kumar *et al.,* (2005) and Kumari *et al.,* (2017) also reported an increase in bacterial count with application of different organic N sources compared to control.

Integrated nutrient management (INM) or integrated nutrient supply (INS) help to achieve efficient use of synthetic fertilizers integrated with organic sources of nutrients (Mahajan *et al.,* 2008). INM is developed with an understanding of the interactions among crops, soils, and climate, which advocates the integration of inorganic and organic sources of nutrients. This approach is based on the maintenance of plant nutrition supply to attain a certain level of crop production by enhancing the benefits from all potential sources of plant nutrition in a cohesive manner, applicable to each cropping pattern and farming scenario (Mahajan and Sharma, 2005). The inclusion of organic manures regulates the uptake of nutrients, positively affecting production, improving soil quality (physical, chemical, and biological), and producing a synergistic effect on crops (Yadav and Kumar, 2000). INM integrates traditional and recent practices of nutrient management into an environmentally sound and cost-effective ideal farming system that uses remunerations from all probable sources of nutrition (organic, inorganic, and biological) in a careful, effective, and combined way (Wu and Ma, 2015). It optimizes the balance between input sources and outputs with the goal of coordinating the nutritional demand of the crop and its discharge in its surroundings (Fig. 4).

The integrated application of organic and inorganic fertilizers for 29 years reduced soil reactions by 0.22% over the application of inorganic fertilizers alone (Kumar *et al.,* 2017).The effects of INM on nutrient dynamics were recorded, and it was concluded that combining FYM with inorganic fertilizers could maintain SOC and available N and Pat either equal to or greater than the initial soil nutrient levels, thus maintaining soil fertility even under continuous cultivation (Chaudhary *et al.,* 2017). Incorporation of rice straw with green manure along with inorganic fertilizers increased Av. P by 12.7% and Av. K by 14.3%, as compared to treatments in which only inorganic sources of nutrients were applied (Kharub *et al.,* 2004). Sesbania green-manuring in rice, integrated with inorganic fertilizers, increased the available N from 5.8 to 22.0 kg ha^{-1}, Av. P from 1.4 to 3.8 kg ha^{-1}, and Av. K from 2.2 to 17.9 kg ha^{-1} (Paikaray *et al.*, 2002) (Table 9).

Liu *et al.*, (2014), in agricultural soils under 40 t ha^{-1} biochar, soil water stable aggregate (> 0.25 mm) in the 0–15 cm soil layer had a remarkable increase respect to other treatments, especially the macro-aggregate with particle size larger than > 2 mm, suggesting that biochar incorporation into soil improves soil structure (Fig 5b). Lucas *et al.*, (2014) demonstrated that organic amendments containing high amount of bioavailable C derived from cellulose, can promote fungal proliferation and improve soil structure through stabilization of soil aggregates, suggesting a use of organic amendments to manipulate soil microbial community structure and to promote aggregation in soils. The application of organic amendments in the form of compost is an effective tool to recover soil organic C stock (Zhang *et al.*, 2015). Organic amendments, once added to the soil, favour the growth and diversity of microbial communities, highlighting a strong correlation between soil biological fertility and soil organic C content (Chakraborty *et al.*, 2011).Bonanomi *et al.,* (2011a) who compared the biological characteristics of soils collected from different agricultural farms in a multidisciplinary approach. They found a drastic reduction of soil microbial biomass, fungal mycelium and all enzymatic activities in soils having small organic C content and under intensive agriculture without use of organic amendments.

The use of compost can affect soil microbial diversity, as reported by Zaccardelli *et al.*, (2013a) who showed a clear positive effect on the number of spore-forming bacteria, with an increase directly correlated with the dose of compost. Also in stressed soil, with high saline content, the use of compost can determine an improvement of biological fertility (Lakhdar *et al.,* 2009). Ouni *et al.*, (2013) investigated the effects of composts, produced by MSW and palm wastes, at several doses (0, 50, 100, and 150 t ha^{-1}) on saline soil. They observed an increase of soil organic matter and consequently an improving of microbial biomass and several enzyme activities but the results were different in presence of the highest dose of compost (150 t ha^{-1}), where a reduction of some activities was registered. This behaviour could be likely attributed to the potential toxic effect of the trace elements present in this particular compost (Crecchio *et al.,* 2004).

Ding *et al.*, (2016) reported that manures and composts contain pathogens, heavy metals, and pharmaceuticals, which may cause long-term contamination of farmland. Moreover, manures and composts have the potential to lead to ammonia and methane releases, which can aggravate global warming and serious groundwater and stream nutrient pollution. Being a renewable resource and due to its economic and environmental benefits (Fig. 6a), biocharis a promising resource for soil's fertility management. Furthermore, biochar loaded with ammonium, nitrate, and phosphate could be also proposed to be a slow-release fertilizer to enhance soil fertility (Xu *et al.,* 2014; Schmidt *et al.,* 2015;

Kammann *et al.,* 2015).In order to better understand the connections between biochar and soil, four following aspects are included in this paper (Fig. 6b): (i) biochar as a source of nutrients; (ii) adsorption and desorption of nutrients on biochar; (iii) the influence of biochar on properties of soils; and (iv) the effects of biochar on biota in soil. Biochar has high total porosity and it could both retain water in small pores and thus increase water holding capacity and assist water to infiltrate from the ground surface to the topsoil through the larger pores after heavy rain (Asai *et al.,* 2009). Peake *et al.,* (2014) indicated that biochar application could increase available water capacity by over 22 %. Nelissen *et al.,* (2015) demonstrated that biochar application could increase available water capacity from 0.12 to 0.13 m^3 m^{-3}.Laird *et al.,* (2010) indicated that the biochar treatments significantly increased cation exchange capacity by 4 to 30 % and relative to the controls.

Wang *et al.,* (2014) indicated that the amounts of the extractable K, Ca, Na, and Mg approximately increased by ranging from 60 to 670 % after biochar addition. For example, the K content of soil increased from 42 to 324 mg kg^{-1} (Wang *et al.,* 2014). In addition, biochar treatment could increase base saturation percentage from 6.4 to 26 % and saturated hydraulic conductivity from 16.7 to 33.1 cm h^{-1}, decrease soil erosion rate from 1458 to 532 g m^{-2} h^{-1} (Jien and Wang 2013), and increase total C from 2.27 to 2.78 % and total N from 0.24 to 0.25 % and available P from 15.7 to 15.8 mg kg^{-1} (Jones *et al.,* 2012). These improvements in soil chemical properties could increase soil fertility by increasing the nutrient contents and availability. Deenik *et al.,* (2010) and Spokas *et al.,* (2011) indicated that biochar with high volatile matter content, which produced at higher temperature, contributed to N immobilization and microbial activity reduction which could inhibit plant growth.

The possible improvements of soil's properties and fertility after biochar application were shown in Fig. 6c. On the one hand, the properties of soils, containing physical, chemical, and biological properties, could be improved after biochar treatment. Moreover, the improvement of soils properties is highly related to the specific physicochemical properties of biochar, such as high surface area, amount of functional groups, and the content of liming. For example, soil's cation exchange capacity may increase with the increase of carboxylic groups and surface area. The well-developed pore structure may not only enhance the capacity of water retention but also provide a shelter for soil's micro-organisms, thus nutrient retention and cycling could be improved. The content of liming contained in biochar may increase soil's pH values. On the other hand, biochar could increase plant nutrient availability in soils by releasing nutrients, retaining nutrients, reducing nutrients leaching, and mitigating gaseous N losses. Therefore, biochar has great potential in the improvement of soil fertility.

Effect of INM on grain quality of rice

Ebaidand El-Hissewy, (2000) indicated that increasing nitrogen fertilizer levels from 0 up to 165 kg N ha^{-1} significantly increased hulling percentage in Sakha 101 rice cultivar. The highest values of hulling percentage were observed at 165 kg N ha^{-1}, followed by 110 kg N ha^{-1}. This increase could be attributed due to the application of nitrogen increased grain-filling rate consequently decreased the hull thickness. These findings are in close agreement with those of reported by Metwally *et al.,* (2011b).

Sravan and Singh (2019) stated grain protein content and yield of basmati rice differed significantly due to varied fertility levels and bio-inoculants showed higher protein content because of more N content in grain. Similar differences in protein content of cultivars were also noted (Ghosh *et al.,* 2004; Chandel *et al.,* 2010; Singh and Sravan, 2017). Higher protein content and yield with use of bio-inoculants might be due to continuous N supply and its efficient translocation to grain; greater nitrogen content in grain customized the proportion of grain constituents (Yadav and Singh, 2013). Integrated nutrient management recorded maximum values for quality characters, application of entire nutrients as inorganic source exhibited 4.2% lower milling than use of organics in combination. FYM supplied macro and micro nutrients in optimum quantities, resulted enhanced quality. Quality parameters improved with combined use of organic and inorganic nutrient sources (Dixit and Gupta, 2000), incorporation of FYM significantly increased the hulling per cent in rice (Prakash *et al.,* 2002). Maximum improvement in hulling, milling and head rice recovery occurred by BGA + *Azospirillum* (B3) was due to enhanced availability of nitrogen for longer duration. Differences in hulling, milling and head rice recovery with bio-inoculants were also reported (Quyen and Sharma, 2003; Davari and Sharma, 2010).

Gharieb *et al.,* (2017) reported that the combination of organic and inorganic sources of nutrients is necessary for sustainable agriculture that can ensure quality crop. The interaction between nitrogen and compost had a significant effect on hulling percentage in 2013. The highest values of HP were recorded with the combination of 165 kg N and 3.5 or 7 t compost ha^{-1}. There were no significant deference between 110 and 165 kg N combined with 7 t compost ha^{-1}. Moreover, the lowest values of HP were obtained under zero nitrogen and zero compost combination (Table 10). Saha *et al.,* (2007) reported that inorganic sources of nutrients influenced more than organic sources on crop growth and quality. Broken rice percentage was significantly controlled by the application of nitrogen in the two seasons. Increasing nitrogen fertilizer from 0 to 165 kg N ha^{-1} decreased significantly broken rice percentage. Moreover, the highest values of broken rice percentage recorded when nitrogen was not applied. This result was also documented by Srivastava *et al.,* (2009) and Ebaid and El-Hissewy (2000). Compost rate influenced significantly on broken rice percentage in both seasons and it decreased with increasing compost. The lowest broken rice percentage was obtained at 7 t compost ha^{-1}, followed by (3 tha^{-1}). Pandey *et al.,* (1999) found higher head rice per cent with the application of of 10 t compost ha^{-1}.

Saha *et al.,* (2007) reported that the protein content in grains was the highest, 8.98%, in the inorganic treatment (100:60:40 kg N, P, K ha^{-1}) and lowest, 7.55%, in the control. Among organic treatments, farmyard manure at 10 Mg ha^{-1} contributed the least in terms of the protein content of the rice (7.78%). Significantly higher iron content, of 52.2 μg g^{-1}, was recorded with organic fertilization than inorganic fertilization (42.1 μg Fe g^{-1}). However, inorganic fertilization was superior in terms of copper content, of 4.1 μg Fe g^{-1}, compared with organic treatments: 3.1–4.0 μg Fe g^{-1}. Quality attributes indicated that cooked kernel length was positively correlated with the kernel elongation ratio. Winter weed compost provided comparative benefits for rice yield (3.87 Mg ha^{-1}) and quality in terms of protein (8.42%), iron (48.31 μg g^{-1}) and head rice recovery (49.39%) compared with other sources of nutrients.

Kumar (2010) revealed that kernel length and kernel breadth before and after cooking were higher in treatments getting higher proportion of inorganic-N. Hulling and milling percentage and shape index before and after cooking were not affected markedly. Head rice recovery was higher in the treatment receiving higher proportion of organic-N.

Benefit of organic manure comes through changes in soil properties for which a minimum of four to five years application would be essential (Table 11). Similar findings were reported by Munda, (2009). Imade *et al.*, (2017) found protein content and protein yield were increased significantly due to application of general RDF (RDF + FYM @ 10 t/ha) closely followed by 75% RDN through chemical fertilizer + 25% RDN through vermin-compost. The increase in protein content of rice grain due to more quantity of nitrogen content in grain, improved metabolic activities in the plant (Subbiah and Kumarswamy, 2000) and the variation in protein yield was observed because of nitrogen uptake associated with its levels of supply as well as plant potential to absorb and utilize. Similar results were reported earlier by Gaud, (2004). Gharieb *et al.*, (2017) observed that there was a significant effect on HP in the two seasons due to the interaction effect of nitrogen levels and ascobiens praying frequencies. The highest values of HP were obtained at three times ascobien spraying along with 165 kg N ha^{-1}in the first season. While, there were no significant differences on HP among ascobien treatments at 165 kg N ha^{-1} in 2013. Whereas, the lowest values of HP were detected without nitrogen fertilizer at all ascobien treatments. Sharada and Sujathamma, (2018) reported that the quality parameters of straw such as Ash content (Mineral) was observed higher in T_8 (20.65 %) and lowest in T_5 (18.16 %), Crude protein (CP) higher was recorded in control 2 (5.62 %) and lowest in T_2 (4.17 %), neutral detergent fiber (NDF) higher in T_{10} (69.43 %) and lowest in T3 (65.08 %), acid detergent fiber (ADF) higher in T_8 (52.03 %) and lowest in T_6 (48.66 %). crude fiber (CF) higher in T_8 (44.44 %) and lowest in T_6 (40.39 %), acid detergent lignin (ADL) higher in T_5 (4.55 %) and lowest in T_3 (3.29 %). ADF, CF, ADL were statistically significant at $P<0.008$ and $P<0.0001$, respectively. Esfahani *et al.*, (2018) reported that the highest amount of gel consistency for cv.Tarom Hashemi was observed with 100 of NPK and 75% of recommended nitrogen and manure consumption. The maximum amylose content for cv. Tarom Mahalli was produced with 100% NPK recommended and manure consumption.

Aulakh *et al.*, (2016) reported that green manuring alone (T_2) and different combinations of green manuring, FYM and chemical fertilizer (T_3,T_4,T_6,T_7 and T_8) had statistically similar brown and milled-rice recoveries as that with recommended nitrogen (T_1) (Table 12). Application of FYM alone (T_5) recorded significantly lower brown and milled rice recoveries than the recommended nitrogen (T_1). Head-rice recovery with green manuring (T_2) and different nutrient combinations (T_3, T_4 and T_6) was statistically at par with that of recommended nitrogen (T_1). The FYM when supplemented with50% RN (T_7) or green manuring supplemented with FYM (T_8) had significantly higher head-rice recovery than that of RN, whereas FYM alone (T_5) had significantly lower head rice recovery than that of RN (T_1). The different nitrogen sources did not differ significantly in respect of minimum cooking time, water-absorption ratio and cooking coefficient. Elongation ratio of grains with different nutrient sources was statistically at par with recommended nitrogen. However, the highest elongation ratio was ob-served in FYM + 50% RN (T_7) and it was significantly more than GM+50% RN (T_4) and FYM + 25% RN (T_6).Grain protein content with green manuring (T_2) was statistically similar to that of RN (T_1). The grain protein content was significantly higher by 3.9 and 2.3% than the RN when FYM was supplemented with 50% RN (T_7) and green manuring (T_8), respectively. Significantly lower grain protein content than that of RN was observed with FYM (T_5) and FYM +

25% RN (T_6). The higher protein content and increased elongation ratio with organic manures might be owing to uninterrupted availability of N coupled with increased absorption and assimilation by plants (Rao *et al.*, 2006).

Table.1 Effect of different treatments on growth and yield of paddy [Source: Virdia and Mehta, 2008]

Treatments	Plant Height (cm)	Effective tiller (m^{-2})	Panicle length (cm)	Yield (t/ha)	
				Grain	Straw
Pressmud @ 5t/ha + RDF(80:30:0)	100	329	23.7	5.041	**5.695**
Pressmud @ 10t/ha + RDF	100	326	23.4	5.102	**5.749**
Pressmud@ 15 t/ha+ RDF	100	331	23.6	5.214	**5.838**
Pressmud @ 20t/ha +RDF	100	330	23.8	5.358	**5.952**
Farm yard manure (FYM) @ +10t/ha RDF	101	327	23.8	5.246	**5.787**
RDF alone.	99	327	23.3	5.069	**5.597**
CD(P=0.05)	**NS**	**NS**	**NS**	**0.125**	**0.217**

Table.2 Effect of organic and inorganic fertilizers on different growth and yield parameters of rice [Source: Khan *et al.*, 2007]

Treatment	Plant Height (cm)	Tillers m^{-2}	Panicles m^{-2}	Spikelet $Panicle^{-1}$	1000 paddy Wt.(g)	Paddy yield $t.ha^{-1}$	Straw yield $t.ha^{-1}$
Control	68.67^{e}	181.7^{e}	177.3^{e}	97.7^{e}	18.17^{d}	4.70^{d}	8.82^{d}
NPK alone	76.30^{d}	272.7^{d}	268.7^{d}	110.8^{d}	19.90^{cd}	5.76^{c}	11.13^{bc}
NPK+FYM	88.73^{abc}	283.0^{cd}	279.3^{c}	116.8^{bcd}	22.33^{abc}	6.64^{b}	11.20^{bc}
NPK+GM	90.53^{abc}	294.0^{bc}	289.3^{b}	116.9^{bcd}	21.83^{abc}	6.41^{b}	11.30^{bc}
NPK+Zn(SA)	85.93^{bc}	275.0^{d}	271.0^{cd}	116.0^{bcd}	20.17^{bcd}	6.51^{b}	11.03^{bc}
NPK+FYM+Zn(SA)	89.27^{abc}	306.0^{ab}	301.3^{a}	116.2^{bcd}	22.83^{abc}	7.26^{a}	13.3^{a}
NPK+GM+Zn(SA)	93.53^{a}	315.0^{a}	309.3^{a}	136.5^{a}	23.50^{a}	7.32^{a}	13.93^{a}
NPK+Zn(RD)	85.00^{c}	284.7^{cd}	268.3^{d}	112.1^{cd}	20.90^{bcd}	6.30^{b}	10.6^{c}
NPK+FYM+Zn(RD)	89.4^{abc}	306.3^{ab}	301.3^{a}	121.9^{bc}	22.83^{abc}	7.24^{a}	13.2^{a}
NPK+GM+Zn(RD)	92.67^{ab}	305.3^{ab}	307.0^{a}	125.9^{b}	23.17^{ab}	7.25^{a}	13.2^{a}
LSD 0.05	7.577	13.53	9.109	10.47	3.029	0.3639	1.625

Values followed by the same letter(s) in each column are not significantly different at 5 % level of probability.

Note :Rate of NPK= 120-90-60 kg ha^{-1}, FYM=10 t ha^{-1}, GM=10 t ha^{-1}, Zn (SA) = 10kg ha^{-1} in the form of ZnSO4 fertilizer, Zn (RD) =1.0% in $ZnSO4^{-1}$ (A.R) solution and dipping for 5 minutes. Where NPK:Nitrogen, Phosphorus and Potassium respectively;FYM:Farm Yard Manure;GM:GreenManure; Zn:Zink; SA:Soil Application; RD:Root Dipping;

Table.3 Effect of organic and inorganic sources of nutrient on yield attributes, yield and protein content of rice (Source: Kumar *et al.*, 2014)

Treatment	Panicles/m 2 (No.)	Panicle (cm) length	Panicle s wt. (g)	1000 grain wt. (g)	Grain yield(t/ ha)	Straw yield (t/ha)	Protein (%) content
Control	211.8	23.2	3.1	18.6	4.03	6.23	**7.3**
75% RDF	215.0	23.3	3.2	19.0	4.23	6.6	**7.61**
100%RDF	220.6	25.5	3.2	19.2	4.38	7.02	**7.77**
125%RDF	223.0	25.6	3.3	20.1	4.56	7.49	**7.87**
2.5 t/ha vermicompost	217.3	24.9	3.2	19.3	4.37	6.76	**7.68**
5 t/ha vermicompost	219.0	25.0	3.3	20	4.47	7.33	**7.93**
75% RDF + 2.5 t/ha vermicompost	222.8	26.3	3.2	20.2	4.75	7.72	**8.28**
100%RDF + 2.5 t/ha vermicompost	223.1	26.8	3.3	20.3	4.79	7.78	**8.39**
125%RDF + 2.5 t/ha vermicompost	237.4	27.5	3.4	20.4	4.84	7.78	**8.56**
75% RDF + 5 t/ha vermicompost	228.3	27.2	3.3	20.4	4.94	8.07	**8.5**
100%RDF + 5 t/ha vermicompost	254.3	28.6	3.5	20.5	5.14	8.31	**8.6**
125%RDF + 5 t/ ha vermicompost	255.5	28.6	3.6	21	5.28	8.54	**8.67**
CD (P=0.05)	**20.04**	**2.45**	**0.25**	**1.09**	**0.42**	**0.68**	**0.84**

Table.4 Effect of different sources of organic manures and inorganic fertilizers on growth and yield of rice [Source: Baishya *et al.*, (2015]

Treatments	Plant height(cm)	Tillers No	Panicle length (cm)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
Sesbania **green manure (5t/ha)**	93.03	13.0	17.03	2.23	**4.02**
Sesbania **green manure (5t/ha) 75% CDF**	107.40	13.6	22.00	4.07	**7.12**
Sesbania **green manure (5t/ha) + 100% CDF**	110.33	13.9	23.20	4.43	**7.45**
Sesbania **green manure (5t/ha) + 125% CDF**	114.50	14.1	23.73	4.93	**7.89**
5 t FYM ha^{-1}	93.30	12.4	16.20	3.07	**5.52**
5 t FYM ha^{-1} + 75% CDF	103.50	13.5	17.37	4.63	**7.88**
5 t FYM ha^{-1} + 100% CDF	106.27	14.0	22.07	4.90	**8.18**
5 t FYM ha^{-1} + 125% CDF	110.37	14.3	23.23	5.37	**8.59**
1 t Vermicompost ha^{-1}	93.70	13.3	17.37	4.33	**7.37**
1 t Vermicompost ha^{-1}+ 75% CDF	104.63	14.0	22.93	4.83	**7.73**
1 t Vermicompost ha^{-1}+ 100% CDF	105.03	14.3	23.97	5.17	**8.11**
1 t Vermicompost ha^{-1}+ 125% CDF	110.30	14.5	24.75	5.53	**8.69**
2.5t Poultry manure ha^{-1}	92.47	12.7	17.27	3.87	**6.57**
2.5t Poultry manure ha^{-1}+ 75% CDF	107.47	13.7	23.67	5.33	**8.53**
2.5t Poultry manure ha^{-1}+ 100% CDF	110.40	14.5	24.63	5.60	**8.85**
2.5t Poultry manure ha^{-1}+ 125% CDF	112.27	14.6	24.93	6.03	**9.41**
CD (P=0.05)	**6.24**	**1.3**	**1.40**	**0.25**	**0.43**

Table.5 Effect of fertility levels and bio-organics on yield and yield attributes of rice [Source: Kumar *et al.*, 2017]

Treatments	Panicles m^{-2}	Filled grains $panicle^{-1}$	Unfilled grains $panicle^{-1}$	1000-grain weight (g)	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})	Harvest index (%)
Fertility levels (% RDF)							
0	181.31	166.66	26.66	12.92	31.27	57.15	**35.33**
50	206.91	183.88	22.33	13.70	36.34	63.49	**36.39**
75	214.28	193.33	18.55	13.82	40.28	68.65	**36.96**
100	225.07	200.00	15.44	14.28	42.45	71.24	**37.33**
CD (*P*=0.05)	6.39	6.61	2.39	0.36	0.92	1.96	**0.31**
Bio-organics							
Control	197.78	178.00	23.08	13.24	33.06	58.02	**36.19**
FYM	205.93	188.08	21.00	13.74	38.93	67.49	**36.53**
FYM + BGA	216.98	191.83	18.16	14.06	40.76	69.89	**36.79**
CD(*P*=0.05)	**5.53**	**5.05**	**2.07**	**0.31**	**0.80**	**1.70**	**0.27**

Table.6 Effect of INM on yield attributes, grain, straw yield and harvest index of rice [Source: Tiwari *et al.*, 2017]

Treatments	Panicles (m^2)	Panicle length (cm)	Grains/ panicle	Test wt. (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest Index (%)
T_1:Control	225.9	18.4	98.6	22.80	1440.0	2217.2	39.37
T_2:R25%	276.9	22.6	120.8	22.95	3344.2	4448.0	42.92
T_3:R50%	280.0	22.9	120.9	23.20	3475.0	4586.7	43.10
T_4:R75%	292.7	23.9	127.7	23.35	4138.0	5212.2	43.48
T_5:R100%	324.6	26.5	141.6	23.85	5113.0	6647.2	44.26
T_6:R50%+50%FYM	345.2	28.9	156.1	24.20	5459.0	7042.0	43.67
T_7:R75%+25%FYM	329.3	27.6	148.9	23.30	5208.0	6770.0	43.48
T_8:R50%+50%WCS	304.7	24.5	136.5	23.10	4249.0	5449.7	43.82
T_9:R75%+25%WCS	310.8	24.9	138.2	23.20	4519.0	5919.2	43.29
T_{10}:R50%+50%GM	332.8	27.9	150.5	24.10	5263.0	6736.7	43.86
T_{11}:R75%+25%GM	321.7	27.0	145.5	23.40	5087.0	6561.7	43.67
T_{12}:Farmers practice	290.0	23.7	126.1	23.00	3850.0	5158.5	42.74
CD at 5 %	30.308	2.085	12.112	NS	271.209	353.778	0.977

Table.7 Effect of INM on Grain yield, Straw yield and Harvest index [Source: Singh *et al.*, 2018]

Treatments	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})	Harvest index (%)
T_1:Control	9.35	12.63	**42.53**
T_2: 50%RDF	27.59	35.31	**43.87**
T_3: 75%RDF	36.01	45.02	**44.44**
T_4: 100%RDF	49.12	60.41	**44.85**
T_5: 50%RDF+50%FYM	55.10	66.94	**45.26**
T_6: 75%RDF+25%FYM	50.46	61.05	**45.18**
T_7: 50%RDF +50%WS	52.80	64.39	**45.06**
T_8: 75%RDF+25%WS	49.65	60.57	**45.04**
T_9: 50%RDF+50%GM	54.79	66.29	**45.25**
T_{10}:75%RDF+25%GM	50.27	60.82	**45.25**
CD (P=0.05)	**4.28**	**4.98**	**1.54**

Table.8 Effect of Organic and Inorganic Sources of Nutrients on No. of Effective tillers $hill^{-1}$, Number of spikelets $panicle^{-1}$, Number of filled spikelets $panicle^{-1}$ (%), Test weight (g), Grain Yield (kg ha^{-1}), and Straw Yield (kg ha^{-1})

	Treatment	No. of effective tillers/hill	Number of spikelets/panicle	Number of filled spikelets/panicle (%)	Test weight (g)	Grain Yield (kg/ ha)	Straw Yield (kg/ha)	Grain Protein (%)
T_1	FYM @ 5 tonnes ha^{-1}	5.73	123.07	79.54	22.17	2466.67	7466.67	11.067
T_2	FYM @ 10 tonnes ha^{-1}	6.30	135.47	80.48	22.45	2700.00	8066.67	11.230
T_3	50 % RDF	6.90	143.47	80.39	23.56	2778.33	8200.00	12.143
T_4	75 % RDF	7.40	158.07	82.43	23.74	3300.00	9583.33	12.213
T_5	100 % RDF	8.23	172.93	83.43	23.76	3533.33	10383.33	12.407
T_6	FYM @ 5 tonnes ha^{-1} + 50 % RDF	8.27	164.47	85.50	23.35	3500.00	10333.33	12.617
T_7	FYM @ 5 tonnes ha^{-1} + 75 % RDF	9.17	186.40	85.41	23.56	4133.33	12300.00	12.693
T_8	FYM @ 5 tonnes ha^{-1} + 100 % RDF	9.77	202.13	86.57	23.96	4500.00	12666.67	13.063
T_9	FYM @ 10 tonnes ha^{-1} + 50 % RDF	9.70	198.00	84.36	24.00	4400.00	12583.33	12.993
T_{10}	FYM @ 10 tonnes ha^{-1} + 75 % RDF	11.03	212.47	86.98	24.26	4623.33	13033.33	13.143
T_{11}	FYM @ 10 tonnes ha^{-1} + 100 % RDF	11.70	230.40	87.67	24.66	5016.67	13550.00	13.203
T_{12}	No manure and fertilizer	5.10	114.40	77.49	22.00	2033.33	7016.67	10.000
	F test	S	S	S	S	S	S	S
	SEd (±)	0.28	10.95	1.68	0.73	297.61	691.72	0.93
	CD (P= 0.05)	0.59	22.71	3.48	1.52	617.21	1434.55	1.93
	CV (%)	4.18	7.88	2.47	3.83	10.18	8.12	9.31

*RDF- Recommended Dose of Fertilizer through inorganic fertilizers *i.e.*, 70-40-40 kg ha^{-1} (N-P-K) FYM: Farmyard Manure

Table.9 Status of organic carbon, available N, P_2O_5 and K_2O in post-harvest soil [Source: Baishya *et al.*, 2015]

Treatments	Organic carbon (g kg^{-1})	Available N (kg ha^{-1})	Available P_2O_5 (kg ha^{-1})	Available K_2O (kg ha^{-1})
***Sesbania* green manure (5t/ha)**	7.8	166.6	23.3	**61.0**
***Sesbania* green manure (5t/ha) + 75% CDF**	7.9	181.6	28.1	**74.0**
***Sesbania* green manure (5t/ha) + 100% CDF**	8.1	193.3	28.4	**78.6**
***Sesbania* green manure (5t/ha) + 125% CDF**	8.8	198.7	29.0	**80.0**
5 t FYM ha^{-1}	8.1	182.0	25.7	**81.6**
5 t FYM ha^{-1} + 75% CDF	8.6	188.6	26.8	**73.8**
5 t FYM ha^{-1} + 100% CDF	8.9	198.1	27.7	**78.5**
5 t FYM ha^{-1} + 125% CDF	9.0	202.3	28.1	**80.5**
1 t Vermicompost ha^{-1}	7.9	185.0	23.5	**80.6**
1 t Vermicompost ha^{-1}+ 75% CDF	8.2	192.3	24.7	**82.6**
1 t Vermicompost ha^{-1}+ 100% CDF	8.5	198.0	25.3	**86.5**
1 t Vermicompost ha^{-1}+ 125% CDF	8.2	202.5	26.6	**90.0**
2.5t Poultry manure ha^{-1}	7.7	183.5	25.6	**79.6**
2.5t Poultry manure ha^{-1}+ 75% CDF	8.9	192.6	28.8	**88.3**
2.5t Poultry manure ha^{-1}+ 100% CDF	9.2	197.3	31.0	**90.3**
2.5t Poultry manure ha^{-1}+ 125% CDF	9.4	203.0	32.0	**92.3**
CD at 5%	**0.6**	**6.82**	**1.71**	**2.7**

Table.10 Hulling, milling and broken rice percentages of rice cv. Sakha 106 as influenced by the interaction between nitrogen rate and compost rate in 2012 and 2013 seasons

KgN ha^{-1}	Compost / t ha^{-1}	Hulling (%)	Milling (%)	Broken rice (%)	
		2013	2012	2012	2013
0	0	81.79 f	70.25 g	12.53 a	11.95 a
	3.5	82.17 e	71.86 f	11.18 b	10.85 b
	7	82.37 de	72.66 ef	10.57 bc	10.50 bc
55	0	82.22 e	73.00 ef	9.780 cd	10.30 bcd
	3.5	82.44 cde	73.22 def	8.990 de	9.980 cde
	7	82.62 bcd	74.12 cde	8.780 de	9.600 ef
110	0	82.49 cde	74.16 cde	8.960 de	10.43 bc
	3.5	82.67 bcd	74.81 bcd	8.500 e	9.480 ef
	7	82.83 ab	75.46 abc	8.280 e	9.240 fg
165	0	82.71 bc	76.00 ab	8.790 de	9.830 def
	3.5	82.86 ab	77.05 a	8.640 de	8.790 g
	7	83.05 a	77.08 a	8.300 e	8.010 h

Means of each column designated by the same letter are not significantly different at 5% level using Duncan's multiple range test.

Table.11 Hulling, milling, broken rice and amylose percentages of rice cv. Sakha 106 as affected by the interaction between nitrogen rate and foliar application of ascobien in 2012 and 2013 seasons

Kg N ha^{-1}	Ascobien spray	Hulling (%)		Milling (%)		Broken rice (%)	
		2012	2013	2012	2013	2012	2013
0	0	83.46 g	81.90 f	70.61 h	71.27 i	12.87 a	11.88 a
	2 times	84.51 ef	82.16 ef	71.78 g	71.49 h	11.63 b	11.46 a
	3 times	85.46 cd	82.28 de	72.38 fg	71.58 gh	9.770 d	9.96 bcd
55	0	84.06 f	82.31 de	72.66 fg	71.65 gh	10.50 c	11.53 a
	2 times	85.11 de	82.44 cde	72.94 f	71.78 fg	8.750 ef	10.33 bc
	3 times	86.02 bc	82.53 bcd	74.74 de	71.96 ef	8.480 ef	9.500 de
110	0	85.02 de	82.57 bcd	74.27 e	71.99 e	8.980 ef	10.37 b
	2 times	85.52 cd	82.66 bc	74.34 e	72.12 de	8.490 ef	9.770 cd
	3 times	86.35 b	82.76 abc	75.81 bc	72.30 cd	8.280 ef	9.030 ef
165	0	85.66 cd	82.78 ab	75.49 cd	72.38 bc	9.010 e	9.520 de
	2 times	86.34 b	82.84 ab	76.64 b	72.52 ab	8.500 ef	8.810 fg
	3 times	87.03 a	83.00 a	78.00 a	72.65 a	8.220 f	8.310 g

Means of each column designated by the same letter are not significantly different at 5% level using Duncan's multiple range test.

Table.12 Effect of INM treatments on grain and cooking quality of basmati rice

Treatment	Rice recovery (%)			Minimum cooking time (min)	Water absorption ratio	Elongation ratio	Cooking coefficient	Protein content (%)
	Brown	Milled	Head					
T_1 (RN)	77.7	68.4	54.4	16.44	3.27	1.61	5.45	7.37
T_2 (GM)	77.6	68.9	55.5	16.46	3.22	1.62	5.71	7.36
T_3 (GM + 25% RN)	76.7	68.1	52.9	16.45	3.15	1.60	5.45	7.40
T_4 (GM + 50% RN)	76.2	67.2	52.4	16.35	3.16	1.56	5.68	7.48
T_5 (FYM)	74.8	65.9	51.1	16.30	3.13	1.58	5.48	7.18
T_6 (FYM + 25% RN)	77.3	69.6	54.2	16.42	3.21	1.57	5.56	7.18
T_7 (FYM + 50% RN)	78.7	70.3	57.3	16.48	3.26	1.63	5.58	7.66
T_8 (FYM + GM)	78.1	69.6	56.7	16.48	3.17	1.62	5.56	7.54
T_9 (Control)	73.3	64.4	49.1	16.35	3.09	1.56	5.52	7.05
SEm±	0.67	0.70	0.73	0.09	0.07	0.02	0.23	0.04
CD (P=0.05)	2.0	2.1	2.2	NS	NS	0.05	NS	0.12

T_1, (RN), Recommended nitrogen 40 kg N/ha; T_2, (GM), green manure; T_3, GM + 25% RN; T_4, GM + 50% RN; T_5, (FYM) farmyard manure to supply 40 kg N/ha; T_6, FYM + 25% RN; T_7, FYM + 50% RN; T_8, FYM + GM; T_9, unfertilized control

Fig.1 Tiller number (a) and Dry matter (t ha^{-1}) [b] of rice as affected by organic fertilizers at the critical growth stages [Source: Moe *et al.*, 2019]

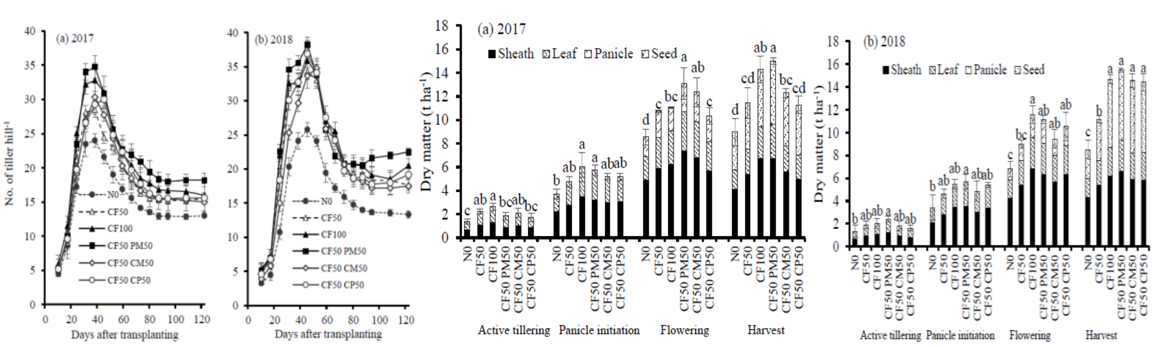


Fig.2(a): Changes in biomass accumulation during at early (**A**) and late season (**B**), N accumulation during early (**C**) and late season (**D**), nitrogen use efficiency during early (**E**) and late season (**F**), and root-to-shoot ratio during early (**G**) and late season (**H**) of rice at the tillering, heading, and maturity stages under organic manure and inorganic fertilizer application [Source: Iqbal *et al.*, 2019].

Note—T_1: no N fertilizer, T_2: 100% CF, T_3: 60% CM + 40% CF, T_4: 30% CM + 70% CF, T_5: 60% PM + 40% CF, T_6: 30% PM + 70% CF.

Fig. 2(b): Tillering pattern of hybrid rice as affected by combined application of organic manures and inorganic fertilizers in (a) dry season and (b) [Source Moe *et al.*, 2017].

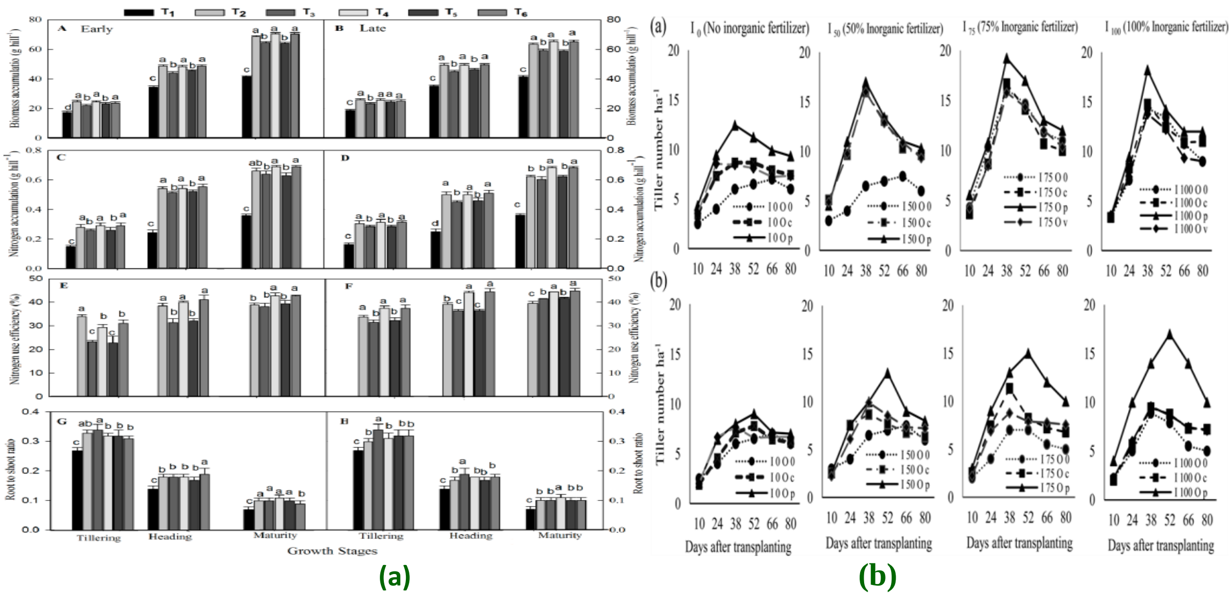


Fig.3 Effect of mixing organic and inorganic fertilizer on soil fertility and productivity

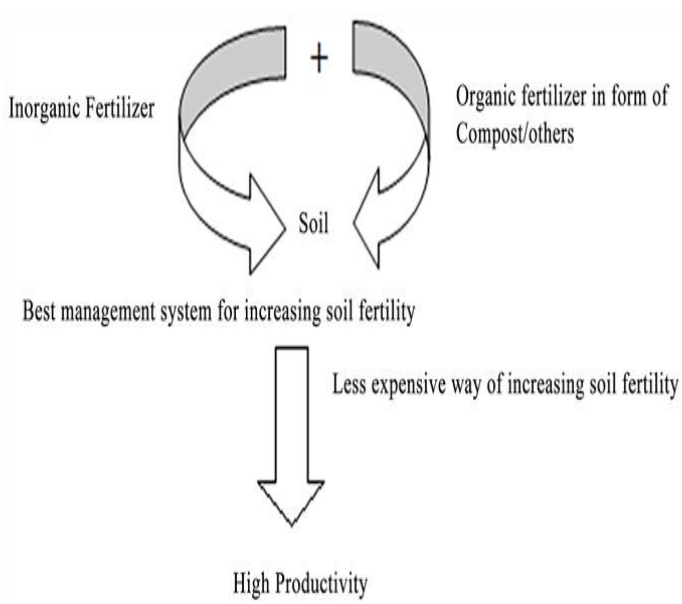


Fig.4 Mean of nutrients for inputs and outputs, and the principles of integrated nutrient management systems [Source: Wu and Ma, 2015]

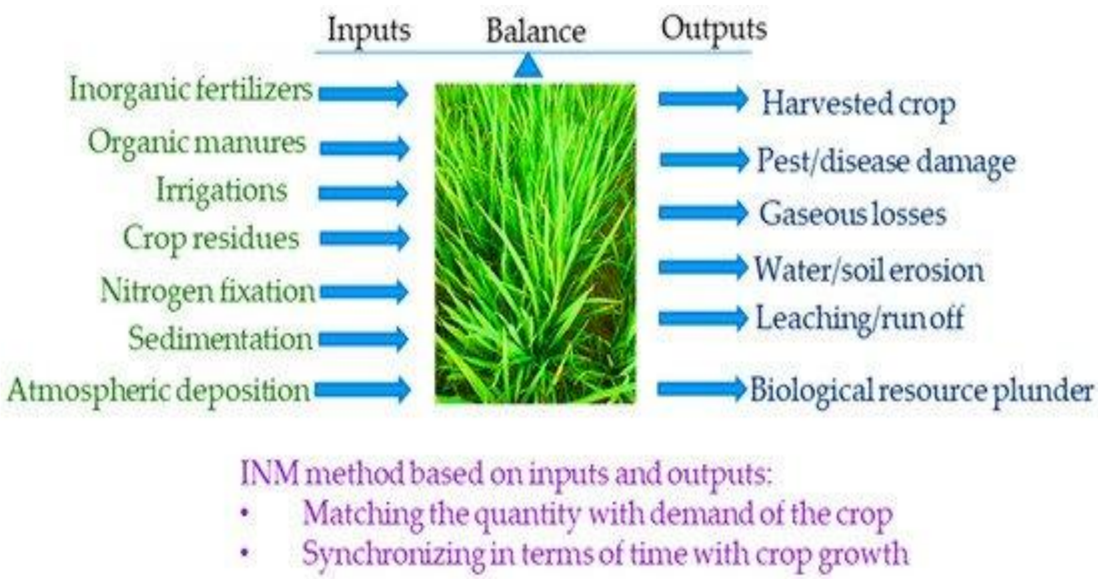
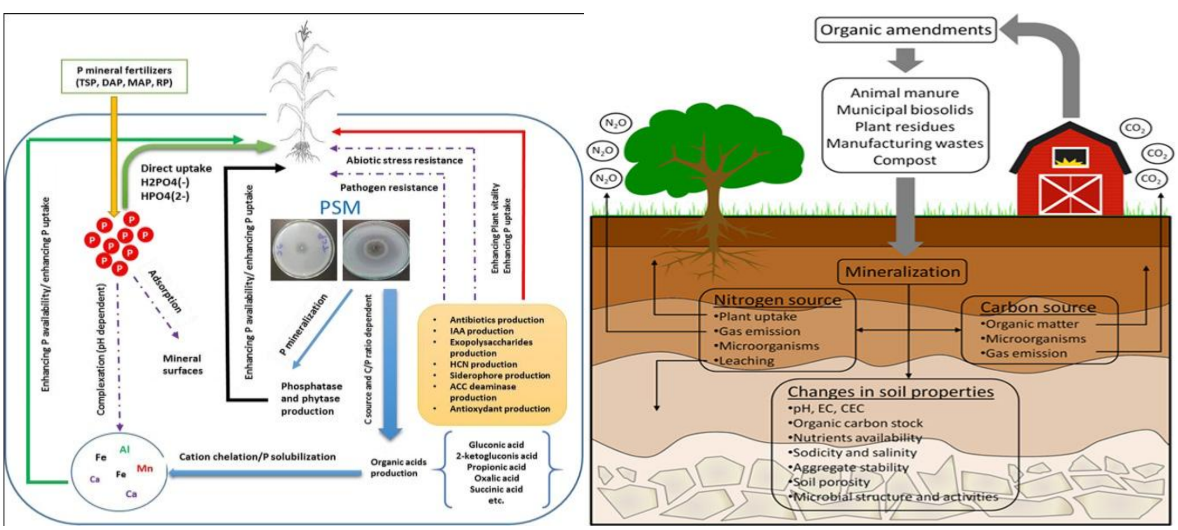
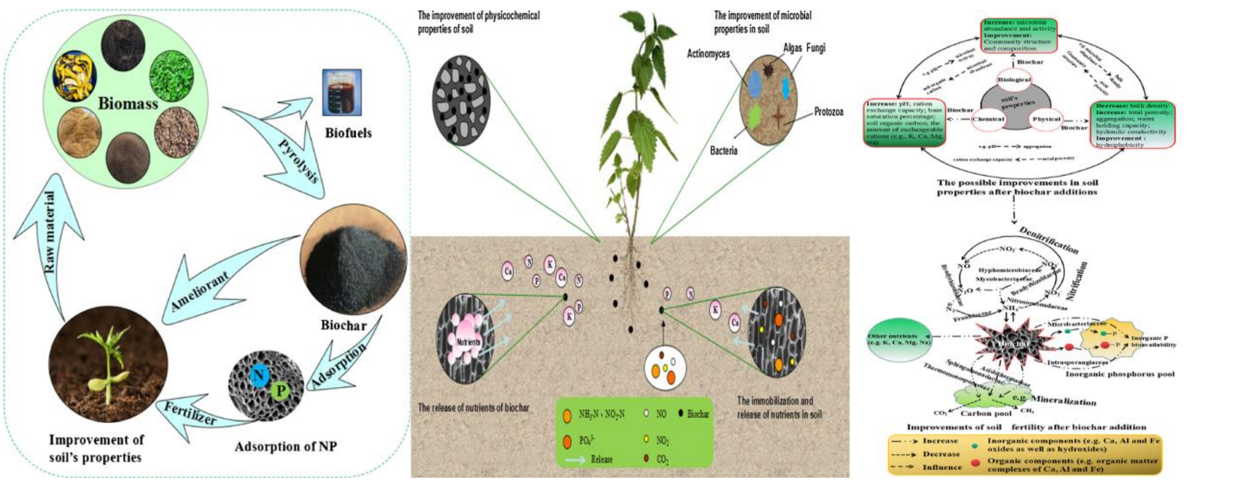


Fig. 5 (a): Role of P solubilizing microorganisms (PSMs) in enhancing P mineral fertilizers eco-efficiency. PSM increase bioavailable P either directly by the production of low molecular weight organic acids, thus chelating through their carboxylic groups, cations attached to insoluble P, or indirectly by synthetizing bioactive molecules (phytohormones, siderophore, antibiotics, etc.) which improve plant vitality and resilience to biotic and abiotic stress and ultimately leads to better nutrients uptake and agronomic yield.
Fig. 5(b): Schematic representation of the effect of organic amendments on soil properties by acting as a source of carbon and nitrogen



(a) (b)

Fig. 6(a): The benefits of biochar applied as a tool for soil fertility management
Fig. 6(b): The possible mechanisms for improving soil fertility
Fig. 6(c): The possible improvements of soil properties and fertility after biochar application



(a) (b) (c)

In conclusion, this review paper emphasized the role and importance of an integrated nutrient management system *i.e.* organic and inorganic nutrient sources as a management strategy that can bring sustainability to the rice crop of the Indian subcontinent. Organic fertilizers have more benefits in the long run compared to inorganic fertilizers. Organic fertilizer improves physical, biological, and chemical properties of a soil but the nutrients may not be as readily available to the plants. However, inorganic fertilizer is usually immediately and fast containing all necessary nutrients that are ready for plants. The excess use of inorganic fertilizers in agriculture can lead to soil deterioration, soil acidification and environment pollution. The integrated soil fertility management system is an alternative approach for the sustainable and cost-effective management of soil fertility and is characterized by reduced input of inorganic fertilizers and combined use of inorganic fertilizers with organic materials. Combined applications of organic and inorganic fertilizers improve soil fertility, productivity and reduce the impact of inorganic fertilizer on environment. So, it is an alternative way for sustainable soil fertility and productivity. On the basis of foregoing discussion it can be concluded that integrated use of fertilizers along with organics enhanced the productivity of rice. Combined application of farm yard manure, vermin-compost, bio-fertilizers, blue green algae and other organics with 100% RDF resulted in good growth parameters, yield attributes, significantly higher yield, grain quality of rice. Integrated nutrient management strategies provide the scientific basis for balanced fertilization not only between the fertilizer nutrients themselves but also that with the soil available nutrients. Integrated treatments involving inorganic and organic sources had pronounced influence in improving available nitrogen status as well as microbial activity compared to recommended dose of fertilizers. Moreover, the combined application of FYM + BGA with 100% RDF resulted in good growth parameters, yield attributes and significantly higher yield. Finally, the findings suggested that INM may be one of the viable nutrient management options in the Indian subcontinent, particularly for the rice crop.

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