Environment and Ecology 41 (2A) : 1028—1039, April– June 2023
ISSN 0970-0420

An Overview of How INM Influences the Performance of Upland Rice under Changing Climate

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Received 11 October 2022, Accepted 31 March 2023, Published on 17 May 2023

ABSTRACT

Upland rice is grown annually on about 17 million ha worldwide. Out of the total area, 10.5 million ha is in Asia. Brazil is the largest producer of upland rice in the world. In India, 13% of the total area contributes only 4% of the rice production. Mismanagement has led to the degradation of millions of acres of land through erosion, compaction, salinization, acidification, and pollution by heavy metals. Over application of fertilizers, while inexpensive for some farmers, induces neither substantially greater crop nutrient uptake nor significantly higher. To achieve healthy growth and optimal yield levels, nutrients must be available not only in the correct quantity and proportion. Therefore, an integrated nutrient approach which attempts to achieve tight nutrient cycling with synchrony between nutrient demand by the crop and nutrient release in the soil, while minimizing losses through leaching, runoff, volatilization, and immobilization is the solution as the managed nutrients will have a major impact on plan growth, soil fertility, and agricultural sustainability. In this review, the influence of INM on performance of upland rice and the potential of different organic manure such as humic acid, dassagavya, panchagavya, rice husk compost, seaweed, pig manure, which increase the yield of upland rice is discussed. The use of foliar application of organic manure and speciality fertilizer are also mentioned.

Keywords Upland rice, Humic acid, Rice husk compost, Seaweed, Pig manure, Enhanced-efficiency fertilization.

INTRODUCTION

Rice (*Oryza sativa* L.) is the most important and extensively grown crop in tropical and subtropical regions of the world and a staple food for more than 70% of the world population. India has the largest area under rice cultivation in the world and is the second largest producer of rice after China, contributing about 20% of the world rice production (Singh *et al.* 2012). In India, rice is grown over an area of 43 million hectares with total production of 95 m t amounting to 40% of the total food production (Kumar *et al.* 2017).

Rice grown in rain-fed, naturally well-drained soils, without surface water accumulation and normally not bunded is called upland or aerobic rice. Land slopes vary from 0 to more than 30%. It is mainly sown as direct seeded rice and is a resource conservation technique which can be grown under drought prone areas with minimum number of labours

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and saves 29% of the total cost of transplanted crop. The additional benefits of direct seeded rice would be water conservation, soil temperature moderation and build up of soil organic carbon status due to residue retention at the surface. Upland rice is grown annually on about 17 million ha worldwide. Out of the total area, 10.5 million ha is in Asia, 3.7 million ha is in Latin America and 2.8 million ha is in Africa. Brazil is the largest producer of upland rice in the world. Average yield of upland rice in Brazil is about 2 t ha^{-1}. In India, 13% of the total area contributes only 4% of the rice production mainly located at West Bengal, Assam, Bihar, UP, MP. Total area under upland rice is 6.0 m ha, production is 6.0 m t and productivity are 1 t ha^{-1}.

Use of fertilizers in conventional rice cultivation has been reported to have poor nutrient use efficiency due to excessive use of water and readily available nature of nutrients in fertilizers and their ready loss by leaching and volatilization. But total replacement of fertilizer by manures to avoid such losses may not be an easy alternative as manures contain lower nutrient concentration. The use of inorganic fertilizer to sustain cropping was found to increase yield only for some few years but on long-term, it has not been effective and leads to soil degradation. On the other hand, continuous application of organic fertilizer alone on rice field resulting low yield and low N and K content at the mid-tillering stage of rice plant. This implies that the need of integrated nutrient management for rice production. Therefore, the combined use of organic manures and inorganic fertilizers help in maintaining yield stability through correction of marginal deficiencies of secondary and micronutrients, enhancing efficiency of applied nutrients and providing favorable soil physical conditions (Gill and Walia 2014). Hence, it is desirable to adopt integrated approach in meeting the nutrient demand of the crop. INM technology is sustainable as compared to modern chemical farming as it relies more on organic inputs.

With the alarming climate change, low resource use efficiency, rainfed farming practice, land fragmentation with the decrease in lowland areas, low resource use efficiency, is the major constrains of rice production. The alternative is to go for upland rice. We need to use organic and inorganic sources in a judicious and balance manner to obtain sustainable crop production.

Upland Rice Cultivation

Upland rice is primarily grown as a subsistence crop but is critical to the food security to the impoverished community that does not have enough lowland rice to meet their needs. In eastern India, upland rice is grown by farmers who also have lowland fields but who face a “hungry month” before lowland crops can be harvested. The upland crop which is harvested earl, bridges the family through a period when food is extremely scarce.

It is known as Modan cultivation in Kerala, grown as first crop under limited areas in rainfed condition. It contributes 13.4% of total rice area in Kerala and average productivity is less than 1t ha^{-1}. Traditional upland rice varieties and high yielding varieties are used for cultivation. Upland rice is cultivated as

1. **Backyards of homesteads**: They are characterized by complete internal recycling of nutrients and organic matter. Plant species are maintained in ecological balance with livestock to meet human needs on a family farm. Homestead gardens comprise a diversity of crop, animal and off-farm enterprises, all of which contribute to the income of the farm family. The area around the house or farmyard is normally planted in a wide assortment of crops that require no purchased inputs and only a low level of management.

2. **Intercrop in coconut**: In coconut garden 75% area are left unused and this area can be used for growing upland rice.

3. **Intercrop in banana:** Banana is planted with spacing of 2m x 2m and the area around the banana can be used for growing upland rice.

4. **Intercrop in pulses:** Cowpea can be raised as an intercrop with rice by sowing 12.5 kg ha^{-1} seed along with rice to serve as a source of green manures. Cowpea at the age of six weeks can be incorporated in the soil adding substantial quantity of green manure and

also reduces weed pressure.

Need for INM

Intensive cultivation of rice has caused considerable damage to the environment and natural resources including build up of salinity or alkalinity, water logging, water pollution, depletion of groundwater and health hazards due to excessive use of agrochemicals and pesticides. To improve physical, chemical and biological properties of soil, organic fertilizer can be applied (Mengi *et al.* 2016). While inorganic fertilizers supply their nutrients immediately to the plants, the organics, such as farmyard manure (FYM) and green manures, improve the physical properties of soil by lowering bulk density, increasing water holding capacity, and improving infiltration rates. Therefore, properly manage INM is required to increase the yield of upland rice.

Potential and prospects of INM in up land rice

a) Enhances availability of both applied and native soil nutrients –decreases soil bulk density and enhance a favorable soil environment.

b) Synchronizes the nutrient demand - use of manures could minimize potential nitrate leaching as they act as slow release fertilizers synchronizing N supply with plant need.

c) Minimizes the antagonistic effects - certain microbes are present in compost and compost extract such as Trichoderma, Rhizobacteria and Pseudomonas are known to stimulate the plant growth. These microbes benefit plant through different mechanism of action including the production of secondary metabolites such as antibiotics and hormone like substance- the production of siderophos, antagonist to soil borne root pathogens, phosphate solubilization and nitrogen fixation. The buffering capacity of the soil against rapid changes due to acidity, alkalinity, and salinity, pesticides and toxic heavy metals.

d) Increases the water holding capacity and infiltration rate- organic manures increase the porosity.

e) Enhancing water and nutrient use efficiency- improved application and targeting of inorganic and organic fertilizer increases the cation exchange capacity of soils and thus increases retention of nutrients against leaching losses and nutrient uptake more efficiently.

f) Sustain and enhances the chemical, biological and physical soil health- physically, it improves soil structure and increases water holding capacity. Chemically, it increases the capacity of the soil to buffer changes in pH, increases the cation exchange capacity (CEC) and reduces phosphate fixation. Biologically organic manures are the source of energy for soil fauna and microorganism which are the primary agent that manipulates the decomposition and release of nutrient in the soil ecosystem.

g) Arrests degradation of soil, water and environment quality- over application of nitrogenous fertilizers is carried away by water, contaminating surface water and underground aquifers. Organic matter permits better aeration, enhances the absorption and release of nutrients and makes the soil less susceptible to leaching.

h) Correction of marginal deficiencies of some secondary and micronutrients-the organic sources contents not only the major nutrient but also some secondary and micronutrients.

i) Control soil and water erosion -keeping the soil covered with crop residue or green manure crops during the periods of expected high rainfall protects the surface soil against.

Influence of INM on Performance of Upland Rice

The combined application of inorganic and organic sources resulted in higher growth, yield and nutrient uptake in upland rice.

INM on growth of upland rice

INM improved the growth characters such as plant height, number of tillers, LAI in upland rice. Dass *et al.* (2009) reported that application of 50% recommended dose of fertilizers (RDF 40:20:20) along with Glyricidia @ 2.5 t ha^{-1} + Azotobactor and PSB @ 2.5 kg ha^{-1} each were found to produce the tallest plants (53.5cm) with the highest number of tillers $plant^{-1}$ (4.2), LAI (3.32) which was better than farmers' practice, FYM @ 2.0 t ha^{-1} along with urea and DAP

@ 25 kg ha^{-1}. This could be due to very high amount of nutrients and fast decomposition of Glyricidia leaves resulting in the early release of nutrients into the soil. Glyricidia leaves decompose twice as fast as cattle FYM and N release is more synchronized with plant demand. Davari and Sharma (2010) reported that combination of FYM +VC resulted in higher increase in growth attributing characters of rice than FYM or VC alone. Mohan and Sharma (2013) also found that the combination of 75% RDF (60:30 NK) + 25% FYM + Azotobacter + PSB + VAM has the highest tiller number. Application of NPK (60:40:40 NPK ha^{-1}) through chemical fertilizer along with FYM and Zn has shown the highest plant height and productive tillers $plant^{-1}$. Thirunavukkarasu and Vinoth (2013) reported higher growth and growth characters in rice with application of VC @ 2.5 t ha^{-1} along with addition N based on leaf color chart critical value less than four. Yadav and Meena (2014) observed taller plant with application of 90 kg N and 40 kg P_20_5 ha^{-1} along with 75 % RD of N as CF + 25 % RD of N as VC + BGA as compared to other treatments in aromatic rice. Paramesh *et al.* (2014) observed significantly higher growth with combined application of 50 % RD of N through CF and 50 % RD of N through VC in aerobic rice. Vijay *et al.* (2014), revealed that growth was noticed significantly increased with 60 + 30 + 30 kg NPK ha^{-1} (inorganic fertilizer) + 30 kg N (bio-compost) and 45 + 22.5 + 22.5 kg NPK ha^{-1} (inorganic fertilizer) + 45 kg N (bio-compost). Application of 120 kg ha^{-1} N with 50% N as chemical fertilizer and 50% N as FYM has recorded the highest LAI, productive tiller $hill^{-1}$ and DMP (Kumar 2016). Borah *et al.* (2016) revealed application of 75 % RD of N through the application of FYM or VC and 25 % RD through CF improved the growth characters upland rice. Imade *et al.* (2017) reported higher values of plant height and tiller number per hill with the application of 100 kg N with 75% N through chemical and 25 % through vermicompost. Yadav *et al.* (2017) observed higher values of plant height (122.1cm) and tillers per row (57.01) at maturity stage with the application of 70 % RD of nutrients as CF +15 % N as VC+15 % N as poultry manure in rice. Aparna (2018) obtained higher growth characters of upland rice with NPK + 5 t ha^{-1} of FYM and live mulching of green manure cowpea. Apon *et al.* (2018) recorded the tallest plant height at 60 DAS with 75% of 60:30 kg NP ha^{-1} + 5 t ha^{-1} of FYM. Singh *et al.* (2018) reported maximum tillers with 50 % of recommended dose (RD) of N and P + 50 % N as FYM at all the growth stages of upland rice.

INM on the root characters

A soil's potential for producing crops is largely determined by the environment that the soil provides for root growth. INM improved the root characters such as root length, root volume and root DMP. Dry matter accumulation and dry root weight (2.89 g hill-1) were recorded the highest with 50% recommended dose of fertilizers (RDF-40:20: 20 NPK kg ha^{-1}) + Glyricidia + Azotobactor + PSB (Dass *et al*. 2009). Rajanna (2010) reported that application of RDF (100:50:50 kg NPK ha^{-1}) along with 10 t FYM ha^{-1} has significantly higher root volume and was on par with poultry manure and vermicompost. Paramesh *et al.* (2014) also found that 50 % RDN CF (100:50:50 kg NPK ha^{-1} RDF) and 50% RDN through vermicompost has shown the highest root length compared to FYM and poultry manure substitution.

INM on the physiological parameter

INM improved the physiological parameters of upland rice such as RLWC, stomatal conductance and chlorophyll content and the following are some examples. Subsurface drip with 100% RDF (150:50:50 NPK kg ha^{-1}) + Humic acid @ 500 mL ha^{-1} treatment was found to have the highest total chlorophyll content (Vanitha and Mohandass 2014). Application of 75 kg N as (FYM) + 45 kg N as (urea) recorded the maximum chlorophyll content (Singh *et al.* 2011). Kumar (2016) also observed that application of 120 kg N i.e. 50% N as chemical fertilizer and 50% N as FYM has the highest RLWC at flowering stage and the stomatal conductance.

INM on yield and yield attributes of upland rice

INM improved yield and yield attributes such as panicle length, number of grains $panicle^{-1}$, number of filled grains, 1000 grain weight, grain yield and straw yield in upland rice. Dass *et al.* (2009) reported that 50% RDF (40:20:20 kg NPK ha^{-1}) +Glyricidia @ 2.5 t ha^{-1} + PSB @ 2.5 kg ha^{-1} + Azotobacter @ 2.5 kg ha^{-1} has the highest number of filled grains $panicle^{-1}$, panicle weigh, grain yield and straw yield due to the combined effect of nutrient supply, synergism and improvement in physical and biological properties of soil. Davari and Sharma (2010) reported that combination of FYM +VC resulted increased grain yield over control by 38 – 49 % in basmati rice. Foliar application of $FeSO_4$ @ 0.25% and $ZnSO_4$ @ 0.50% was registered higher number of filled grains and heavier grains from FYM @ 10 t incorporated plot compared to green leaf manure incorporation (Sagarika 2011). The highest grain yield and straw yield of upland rice was obtained with application of 5 t FYM + 250 kg lime + 20 kg S + 1 kg B ha^{-1} + 50% RDF of 40:20:20 (Singh *et al.* 2012). Higher yield and yield attributes were produced by the treatment NPK (60:60:40 NPK kg ha-1) through chemical fertilizer and poultry litter which was on par with ½ N + PK + ½ N forest litter over sole application of NPK (Dutta and Yhome 2014). Niru *et al.* (2010) reports that scented rice (Birsamati) grown with recommended inorganic fertilizer produced 20.09 % higher grain yield and yield attributing characters when compared with the best organic source combination of green manuring (GM) @ 5 t ha^{-1} + FYM @ 10 t ha^{-1} (3.3 t ha^{-1}). Yadav and Meena (2014) found that application of 75% RND + 25% RND as VC + BGA gave significantly higher panicle m^{-2} (321.1), grains $panicle^{-1}$ (138.2), 1,000-grain weight (22.7 g), grain yield (5.16 tonnes ha^{-1}), straw yield (7.77 tonnes ha^{-1}). Borah *et al.* (2015) reported that application with 75% RDN (40 kg N ha^{-1}) through VC and 25% RDF gave the highest grain yield and straw yield. Application of 5 t ha^{-1} of FYM with live mulching of green manure cowpea (12.5 kg ha^{-1}) and 60 kg N, 30 kg P_20_5 and 30 kg K_20 ha^{-1} is recommended for upland rice in Kerala (KAU 2016). Tiwari *et al.* (2017) reported higher yield and yield attributes in rice with application of 50 % RD (120:60:60 kg NPK ha^{-1}) and 50 % as FYM and was on par with 50 % RD as CF +50 % through green manuring (sesbania). Yadav *et al.* (2017) reported the highest grain and straw yields with the application of 70% RD of N through CF +15% N as VC+15% N as poultry manure in rice. Combined treatment of irrigation and live mulching with cowpea recorded the highest grain yield (Aparna 2018).

Influence of INM on quality parameter

INM improved the quality parameters of upland rice such as protein content, starch, amylopectin, amylase, carbohydrate and the following are some example. Davari and Sharma (2010) reported that in basmati rice Kernal length and breadth before and after cooking was increased with conjunctive application of vermicompost, wheat residue and bio fertilizers, it was significant over vermicompost alone and farm yard manure alone. Starch and amylopectin content was reported the highest with the application of 1/3 N each of FYM, VC, and neem oil cake (T2) and T2+ green manuring of sunhemp has recorded the highest amylase content. While T2 + Blue green algae + Rock phosphate + PSB has shown the highest carbohydrate (Masram 2013). Sekhar *et al.* (2014) Head rice recovery (%) and volume/expansion ratio were not significantly influenced by both the planting methods and varieties and their interaction with the nitrogen sources. Among the nitrogen sources the highest head rice recovery (68.4%), protein and amylase content were noticed with the combined application of 100% recommended nitrogen through fertilizer with 25% recommended nitrogen through FYM. Application of 75% N as chemical fertilizer and 25% N as FYM recorded the highest protein content (Kumar 2016).

INM on nutrient uptake

INM in upland rice improved the uptake of major nutrient such as NPK, micronutrients such as Fe and Zn. Mussorie rock phosphate along with FYM recorded the maximum availability of K. Foliar application of FeSO4 @ 0.25% and $ZnSO_4$ @ 0.50% along with basal dose of FYM @ 10t ha^{-1} resulted in higher phosphorus iron and zinc uptake (Sagarika 2011). Yadav and Meena (2014) found that application of 75% RND + 25% RND as VC + BGA gave significantly highest N uptake (105.7 kg ha^{-1}) and N-use efficiency (57.3 kg kg^{-1}) over other treatments and remained at par with application of 75% RND+25% RND as FYM+BGA. Application of 75% N as chemical fertilizer, 25% N as FYM was reported to have the highest total NPK uptake (Kumar 2016). Application of sesbania and leuceanea @10 t each were found to have significant effect on N-uptake by grain, straw and its total (Meena and Singh 2018). Moreover, Kumar *et al.* (2014) proved that application of organic and inorganic sources of nutrient in combination remarkably increased N uptake in grain (36.81 %) and straw (42.81 %), P uptake in grain (32.62 %) and straw (31.56 %) and K uptake in grain (35.46 %) and straw (25.39 %) of rice crop over control. Tiwari *et al.* (2017) reported significant increase in nutrient uptake with the application of inorganic and organic sources viz., FYM, VC and poultry manure applied as 30 % N basis in rice. Yadav *et al.* (2017) recorded higher protein content and uptake of N, P and K in rice with the application of inorganic fertilizers and FYM, VC and poultry manure.

INM on soil physical properties

INM improved the soil physical properties such as bulk density, porosity and WHC. Soil organic carbon, available P, K, Zn and Mn inorganic fertilizer treatments were significantly lower compared to the treatments involving organic source such as FYM and green manure. Dass *et al.* (2009) reported that 50% RDF (40:20:20 kg NPK ha^{-1}) +Glyricidia @ 2.5 t ha^{-1} + PSB @ 2.5 kg ha^{-1} + Azotobacter @ 2.5 kg ha^{-1} has synergism and improvement in physical and biological properties of soil. It also reduced bulk density of surface soil while the WHC increased. Bandyopadhyay *et al.* (2010) observed that integrated use of NPK and FYM significantly improved the soil organic carbon content by 29.8 and 45.2% compared to NPK and control treatment, respectively. Sepehya *et al.* (2012) recorded increased porosity and WHC due to application of 90 kg N ha^{-1} with 50 % substituted as FYM. Tadesse *et al.* (2013) reported significant WHC with application FYM of 15 t ha^{-1} while soil bulk density decreased. Treatment combination of 90 kg N through 45 kg chemical fertilizer and 45 kg FYM has the lowest bulk density with the highest porosity and water holding capacity (Kumar 2016). Bulk density was also recorded the lowest in live mulching with cowpea (Aparna 2018).

INM on soil chemical properties

INM improved the soil chemical properties such as OC, available NPK, micronutrient and CEC. Banger *et al.* (2009) reported that application of 100:50 kg NP ha^{-1} increased organic carbon soil by 15.9 % while integrated fertilization or organics increased organic carbon by 27.6% compared to control. Singh *et al.* (2009) studies revealed that application of FYM + boron and Azotobacter also increased nutrient uptake and improved soil fertility over the time in terms of available nutrients and increased soil Azotobacter population. Integrated nutrient management, especially with farmyard manure resulted in significant residual effect on succeeding rice crop yield. The most economical treatment in this cropping sequence was application of 60:13:17 kg NPK ha^{-1} + 20 t FYM ha^{-1}. Alom *et al.* (2010) reported improvement in organic matter and the soil physical property with cereal-legume intercropping. Niru *et al.* (2010) reports that maximum available P (24.7 kg ha^{-1}) and maximum gain in soil P (0.7 kg ha^{-1}) was recorded with the application of karanj cake 2.5 t ha^{-1}. Soil available major nutrient NPK and micronutrient Fe and Zn was found to be the highest in plots treated with FYM @ 10 t ha^{-1} and soil application of $FeSO_4$ and $ZnSO_4$ @ 25 kg ha^{-1} each as basal over control (Sagarika 2011). Sepehya *et al.* (2012) reported that 50% NPK through chemical fertilizer and 50% N through FYM has the highest organic carbon, CEC, and available NPK compare to substitution with wheat cut straw and green manure. Choudhary and Suri (2014) reported that application of 90:45 kg NP ha^{-1} along with FYM @ 5 t ha^{-1} increased organic carbon and the available NPK status of the soil in direct seeded upland rice. Available N was recorded the highest in treatment with chemical fertilizer along with poultry litter while available P in treatment with chemical fertilizer (RDF 60:60:40 kg NPK ha^{-1}) along with FYM and available K in treatment with chemical fertilizer + FYM + Zn while control was having lowest available NPK (Rizongba *et al.* 2016). Live mulching with cowpea recorded the highest available N and K (Aparna 2018).

INM on biological properties

INM improved the biological properties and the microbial population. Singh *et al.* (2009) studies revealed that application of FYM + boron and *Azotobacter* increased soil *Azotobacter* population. Application of 100% NP through chemical fertilizer (RDF 150:75:75) along with biofertilizer and VAM were found to have higher population of *Azospirillum, Pseudomonas fluorescens* and AM fungi while application of 75% NP through chemical fertilizer + BF + VAM were obtained to have the maximum population of Phosphobacteria because of the increase microbial load due to application of bioinoculants along with the fertilizers (Maragatham and Martin 2010). Rajanna *et al.* (2012) also reported that application of vermicompost equivalent to 10 t of FYM + jeevamrutha at 100 % N equivalent basis recorded significantly higher microbial population resulted in higher microbial population like total bacteria, fungi, actinomycetes, nitrogen fixers and P solubilizers, which was on par with poultry manure (RDF: 100:50:50 NPK ha^{-1}) as compared to initial microbial population. Basha *et al.* (2017) reported that application of FYM + VC+ green leaf manure each 1/3 of N (RDN: 100 kg ha^{-1}) along with Microbial consortium (Azotobacter + PSB) and biodigester liquid @ 2500 L ha^{-1} has higher soil microbial population of N fixers, PSB and *Azospirillum.*

INM on economics of upland rice

INM improved the economics of upland rice cultivation such as BC ratio and net return. Higher BC ratio (3.68) was obtained with poultry manure equivalent to 10 t of FYM + bio digester liquid at 100 % N equivalent basis, RDF as 100:50:50 (Rajana *et al.*2012). Foliar application of $FeSO_4$ @ 0.25% and $ZnSO_4$ @ 0.50% along with FYM was associated with higher BC ratio (Sagarika 2011). Thirunavukkarasu and Vinoth (2013) reported the highest benefit cost (BC) ratio with VC applied @ 2.5 t ha^{-1} along with N addition based on leaf color chart critical value less than four. Yadav and Meena (2014) recorded the highest net income and BC ratio with the application of 75 % RD of N as CF + 25 % RD of N as VC. Net return and B: C ratio were found the highest in fertilizer dose of 60:30:30 NPK kg ha^{-1} through micro sprinkler (Shahanila, 2015). Borah *et al.* (2015) reported the highest gross and net income with 75% RD of N through VC + 25 % as CF in upland rice. Kumar (2016) recorded maximum net income with the application of 120 kg N ha^{-1} applied as 90 kg as CF, 30 kg through FYM along while the highest BC ratio was recorded with the application of 120 kg N ha^{-1} applied as 90 kg through CF, 30 kg through FYM in upland rice. Tiwari *et al.* (2017) reported maximum gross returns, net returns and BC ratio with the application of 50 % RD of nutrients as CF + 50 % as FYM. Nilay (2017) reported that direct sown upland rice along with Comlizer-D (1000 kg vermicompost + fertilizer ½ the RDF) and integrated weed management were recorded to have higher BC ratio compare to control (RDF: 20: 4.4 : 8.3 kg NPK ha^{-1}). The comlizer was prepared by mixing biofertilizer-enriched vermicompost (1000 kg ha^{-1}) with half of RDF (20: 4.4: 8.3 kg NPK ha^{-1}) just before application.

Efficacy of different sources of organic manure

Benefits of incorporating various organic substances such as plant and animal waste in upland rice is being explored with the aim of improving yield and the gross output of the farmers. It is also aimed at determining the best readily available organic materials that would increase the yield and growth of upland rice varieties and also to determine the responses of the different rice varieties to the organic materials used. Different sources of organic compost and their application in different research work are shown in Table 1.

Recent Advances

GIS-based fertility maps

Geographic Information System (GIS)-based soil fertility mapping has appeared as a promising alter-

Table 1. Different sources of organic compost.

Sources	Compost preparation	
1. Chromolaena compost	For the preparation of composts, cement cisterns of dimension 90 cm height 90 cm diameter were used. Holes of three cm diameter were made at height of 15 cm above the bottom on the four sides of the cistern. Chopped chromolaena +cow dung slurry @ 20% + microbial culture (20 g +rock phosphate 5%. ZnSO4 @ 400 ppm Zn and borax @ 200 ppm was added 30 days before termination of composting	Application of RDF (100:50:50 NPK ha^{-1}) + Chromolaena compost @ 7.5 t ha^{-1} gave the highest root biomass, number of tillers tillers $hill^{-1}$, plant height, yield and yield attributes (Murthy 2012)

Table 1. Continued.

Sources	Compost preparation	
2 Humic acid	Humic substances are absorbed by roots and translocated to shoots thereby enhancing plant growth. It was reported that the incorporation of HAs into soils stimulated root growth as well as stimulated the proliferation, branching and initiation of root hairs and could partially be attributed to enhanced nutrient uptake.	Vanitha and Mohandass (2014) reported that subsurface drip through 100% RDF+ HA treatment recorded higher panicle number m^{-2} (698) filled grain % (69.66), test weight (24.11), grain yield and harvest index (HI) than the rest of the treatments
3 Jeevamrut and panchagavya	Preparation of jeevamrut: Fresh cow dung 10 kg, cattle urine 10L jaggery 2 kg, pulse flour 2kg, fertile soil one handful and water 200L were mixed and incubated for 39-96 hours Preparation of panchagavya: Cowdung 7kg, cow urine 3L, cow's milk 2L, ghee 1kg, yeast 100g, tender coconut water 3L and ripen banana 12 in numbers were mixed	Divya and Babalad (2016) conducted an experiment and higher grain and straw yields were recorded with soil application of jeevamrut @ 500 Lha^{-1} at planting, 30 and 60 DAS + panchagavya foliar spray @ 5% at panicle emergence and flowering stages (3387 kg ha^{-1} and 4632 kg ha^{-1}, respectively) as it contents beneficial microorganisms, gibberllic acid, auxins and other growth promoting hormones present in jeevamrut and panchagavya
4 Biofertilizer and pig manure		Mengi *et al.* (2016) conducted an experiment and maximum plant height (135.37 cm), number of tillers $hill^{-1}$ (9), dry weight (404.63 g), number of panicle m^{-2} (122), number of grains panicle-1 (151), grain yield (25.18 q ha^{-1}), straw yield (54.83 q ha^{-1}) and maximum uptakes of N (23.86%), P (27.47%) and K (21.83%) in the grain were recorded with the application of Biofertilizer + pig manure @ 3.2 t ha^{-1} + Trichoderma compared to control, vegetable seaweed manure @ 25 kg ha^{-1} and vermicompost @ 2.25 t ha^{-1}
5. Compost manure	Compost manure Rice husk and cow dung formulations showed great potential and were success- used in cultivation of upland rice	Application of compost manure @ 10 t ha^{-1} has the highest total N, available P and K and soil Ca and Mg. Increased application of leveled compost manure increases the CEC (Ojobor *et al.* 2017)
	Press mud compost. It is a by-product of sugar industry and for every 100 tons of sugarcane crushed about 3 tons of press mud cake is left behind as by-product. When this byproduct is composted, it converted into very nutritive organic manure, enabling recycling and the final compost products could be used in agricultural field.	Press mud compost @ 6 t recorded highest LAI in upland rice compared to vermicompost and seaweed compost while foliar application of seaweed extract @ 500 ml recorded the highest LAI (Balamurugan *et al.* 2018)
	Seaweed extracts are bioactive substances extracted from marine algae and used in agricultural and horticultural crops, especially in rainfed crops to avoid excessive fertilizer applications and to improve mineral absorption.	

native. Use of such maps as a decision support tool for nutrient management not only be helps in adopting a rational approach compared to farmer's practices or blanket use of ad-hoc recommendation but also reduces the necessity for elaborate plot-by plot soil testing activities. Recent works in this area showed promising results where GIS based fertility maps were used as fertilizer decision support tools. These studies showed that the GIS-based fertility maps, based on soil sampling i.e. one sample per hectare, helped estimate fertilizer requirement in farmers' fields resulted in comparable crop yield and profitability with soil-test based fertilizer recommendation for individual field.

Soil test-based Approach of fertilizer management

Soil test-based fertility management is an effective tool for increasing productivity of agricultural soils that have high degree of spatial variability resulting from the combined effects of physical, chemical or biological processes. Nutrient supplying capacity of soils, crop responses to added nutrients, and requirement of amendment can be assessed by soil testing. Soil test calibration that is intended to establish a relationship between the levels of soil nutrients determined in the laboratory and crop response to fertilizers in the field helps in balanced fertilization through right kind and rate of fertilizers.

Plant-based approach of site-specific nutrient anagement

The plant-based approach of site-specific nutrient management (SSNM) for irrigated rice systems for Asia was developed in the 1990s by the International Rice Research Institute (IRRI) in collaboration with national partners across Asia to address serious limitations arising from blanket fertilizer recommendation for large areas in Asia. The development of SSNM represented recognition that future gains in productivity and input-use efficiency required soil and crop management technologies that are more knowledge intensive and tailored to the specific characteristics of individual farms and fields.

Enhanced-efficiency fertilization (EEF) concept

Plants demands for mineral nutrients during specific times during which there is need to supply the required amount of nutrient. At this point, split application of nutrient is really a tedious task because of this scarcity of labours and high cost of labour wages making the agriculture non-remunerative. Because of that those reasons the concept of EEF came into existence. In EEF concept fertilizer formulations can minimize the various losses and enhance the use efficiency of the nutrients by providing the continuous availability of the plant nutrients throughout the plant growth. Classification of different enhanced-efficiency fertilization are describe in Table 2.

Stabilized fertilizer

These are the fertilizer formulations or products which are stabilized with the treatment of urease and nitrification inhibitors to avoid probable loss due to sudden hydrolysis of urea and oxidation of ammonia in to nitrous oxide. The act of these enzyme inhibitors must function at appropriate situation.

Table 2. Classification of Enhanced-efficiency fertilization (EEF).

1	Nitrogen	1. Slow released fertilizer Urea super granules, Urea super granules, Urea formaldehyde, Isobutylidene diurea, Crotonylidene diurea 2. Controlled-release fertilizers 3. Coated or encapsulated fertilizers such as S-coated urea and polymer-coated urea 4. Stabilized nitrogen fertilizers- Treated with inhibitors for nitrification and urease
2	Phosphorous	1. Coating of water soluble fertilizers with water-insoluble polymers such as DAP, MAP, TSP -DAP-Star by Hi Fert. 2. Urea super granules containing phosphorus and potassium 3. Fluid versus granular water-soluble phosphorus fertilizers such as ammonium polyphosphates and fluid ammonium polyphosphates 4. Phosphate rock for direct application i.e. rock phosphate -acid soil

Customized fertilizers

Customized fertilizers (CF) is a multi-nutrient carrier designed to contain macro and / or micro nutrient forms, both from inorganic and / or organic sources; manufactured through a systematic process satisfying the crop's nutritional needs, specific to its site, soil and stage.

Nano-fertilizers

Nano fertilizer is a plant nutrient which is more than a fertilizer because of following characteristics. They are of nano size (1 nm–100 nm), contains over 200 types of nano size microorganisms to effectively penetrate into the plant body e.g., leaves, trunks and roots within a short time, contains over 100 types of enzymes of various specific functions and non-toxic.

Fluid fertilizers

Fluid is the state of a matter which is neither a liquid nor a gas is called fluid state, fertilizer formulation in these states is called fluid fertilizers. Fluid fertilizers are available in a wide range of products to farmers. Although the term "liquid fertilizer" is commonly used to describe all fluid fertilizers, in reality the two terms do not imply the exact same meaning. Technically, all fertilizers of fluid consistency which can be transferred by pump are called "fluid fertilizers. This is the proper term to use in the broadest sense to describe such materials. There are two general types of fluid fertilizers. One group is called "suspensions" or "slurries", and the other group is referred to as "clear liquids".

Micronutrient chelating fertilizers

Though micronutrients are required by the crop in small quantity their role in production system is significant. During green revolution and early green revolution period micronutrient deficiency was not noticed but as a result of intensive agriculture system and excess mining of the nutrient from the soil resulted in to deficiency of micronutrient during post green revolution era leads to application of the micronutrient as a part of nutrient management. Application of micronutrient elements directly in their original form is not recommended because of toxicity excreted by the crops, therefore there is need to combine micronutrient with other compound to make their use safe that process called chelating.

CONCLUSION

INM improved the growth parameters of upland rice, root parameters, yield and yield attributes, physiological parameters and quality attributes. INM improved soil health by improving the physical, chemical and biological properties of the soil. Different organic sources have the potential to increase the yield of upland rice. It clearly validates the suitability of humic acid as a beneficial fertilizer product and that combined application of organic manures with liquid organic manures like jeevamrut and panchagavya should be applied for increasing productivity with higher nutrient uptake. The organic manures have a slow release of nitrogen due to their slow mineralization, which helped in the availability of nutrients commensurate with the growth of the plants and development and thus resulted in higher yield. The beneficial effect of panchagavya was mainly attributed to the presence of large quantities of IAA and GA which are physiologically active in photosynthesis and other processes. The other organic compounds released during the decomposition of organic matter, provided a better soil environment thus, leading to taller plants, an increased number of leaves, tillers and intern the final yield. INM is economical and environmentally friendly with little pollution hazard.

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