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A review on conjoint application of organic and chemical fertilizers on soil health and productivity of rice-wheat cropping system

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Abstract

Rice-wheat is the most predominant cropping system in India and covers an area of approximately, 10.5 million ha. However, the productivity of crops under this cropping-system has reached a plateau and in fact is showing a decreasing trend in many areas of India where this cropping system is being practiced for a long time. There are reports of declining factor productivity, i.e. increased rate of fertilizers are needed to maintain the current yield level which is cited as the evidence of unsustainability of the rice-wheat cropping system. The prime causes of low productivity of rice-wheat cropping system in IGP area are insufficient and unbalanced amount of macro and micro nutrient. In cultivation of rice, health and nutrient status of soil declined even in irrigated areas due to application of inadequate and unbalanced quantity of fertilizers. About half of the world's population is alive today because of increased food production fueled by mineral fertilizers. Other sources of nutrients are organic fertilizers which are good source of plant nutrients such as N, P, K, Ca, Mg, Fe, etc. as well as other organic constituents. Therefore, continuous use of organic fertilizers reduces the nutrient requirement of the soil considerably. But, it is widely recognized that neither use of organic fertilizers alone nor chemical fertilizers can achieve the sustainability of the yield under the modern intensive farming. Contrary to detrimental effects of inorganic fertilizers, organic fertilizers 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. To correct the deficiencies in the plant nutrient application methods requires development of precision fertilizer customized technology and hence there is need for application of these nutrients in balance quantity as a customized fertilizer (CF) with special reference to location/region specific for attaining optimum growth, development and enhancing the yield of rice. Keeping the above facts in the view, a review entitled "conjoint application of organic and chemical fertilizers on soil health and productivity of rice-wheat cropping system" has and been complied to present the current scenario of conjoint application of organic nutrients to meet the nutritional requirement of rice- wheat system.

Key word: Organic amendments, chemical fertilizers, customized fertilizers, soil health and rice- wheat system

Introduction

In the whole world, chemicals based modern agriculture itself imparts a great role in degradation in soil health, whose priority is always only high crop productivity. In the Agricultural sphere, an extensive knowledge on soil degradation is already present. Consequently, the excessive use of synthetic fertilizers, the systematic deforestation, soil erosion due to high tillage and the action of rains or winds, loss of organic matter and several other factors brought about increasing desertification, the loss of millions of tons of fertile top soil and, indirectly, silted up rivers and lakes, caused soil Stalinization, climate changes and loss of biodiversity. Besides the need for constant monitoring and evaluations of physical-chemical and biological processes to achieve better soil health, it is imperious to keep in mind that soil organic matters are the main agents of nutrient cycling and also have a complex interaction with plants. Any land-use strategy that contributes to a better equilibrium of soil organic matter is able to result in greater crop productivity, at low cost, and contributes to minimize the use of mineral fertilizers or pesticides, favoring high sustainability. To approach the environmental problems it is necessary to act on various fronts, as: (i)

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characterize the soils through their hydrodynamic activity, the dynamics of percolating solutions and their retention of different elements; (ii) to monitor available nutrients and augment their efficiency in plant nutrition; (iii) evaluate changes in soil physical and chemical properties; (iv) evaluate quantitative and qualitative changes of soil organic matter due to application of organic residues; (v) evaluate the effects on the soil microbial biomass and its metabolic activities; (vi) evaluate plant productivity and nutritional status; (vii) investigate the sustainability of the system and its relative dependence on sanitary, technical, and economic aspects. New research lines must be implemented, and one of them is the need for a concentrated effort in including both organic and inorganic fertilizers. It is fundamental to convince the stakeholders responsible for regulation and control of the wellbeing of the environment, to apply these methods to achieve a satisfactory solution for a sanitary treatment of polluting materials, avoiding environmental contamination of rivers, soil and atmosphere and minimizing the production of greenhouse gases.

Chemical Fertilizes

Chemical fertilizers are and will remain the major and most important component of INM system under intensive cropping system as these contribute about 50% to the increase in food grain production for the increased population of our country. About three fourths of fertilizer is consumed in rice and wheat. In the rice–wheat system, the recommended dose of N should be applied to both crops as there is almost no residual effect on succeeding crops. Due to increased availability of native soil P under submergence, rice generally responds to applied P than wheat. Therefore, P application to wheat should be preferred over rice. However, in P-deficient soils, it is very essential to apply P in both the crops. Rice is more responsive to K than wheat and it should be added as per soil test-based recommendation. Increased use of sulphur-free fertilizers like urea, diammonium phosphate (DAP) and muriate of potash (MOP) has accentuated the need of sulphur application. Due to intensive cropping with high nutrient-responsive varieties of rice and wheat widespread deficiencies of micronutrients particularly that of Zn, are emerging as yield-limiting factors. Hence, the deficient micronutrients should be applied through their respective carriers in soil as per the crops' needs. In rice–wheat rotation, if soil is Zn-deficient, it can be applied as soil application as well as foliar spray in both the crops (Ram, 2000).

Pollution Hazards of Chemical Fertilizers

Use of high-analysis fertilizers alone leads to pollution of air, soil and water and contributes to global warming. There is an accumulation of heavy metals such as Cd, Cr, Ni and Pb in soils up to toxic level. Groundwater has also been contaminated with heavy metals. Application of nitrogenous fertilizers alone without using phosphate and potassic fertilizers renders the formation of some specific types of compounds that are carcinogenic. Indiscriminate use of nitrogenous fertilizers without phosphate or potash has damaged the productivity of agricultural land in the long run, spoiling the reputation of fertilizers (Gupta and Singh, 2006).

Indiscriminate consumption of N, P_2O_5 and K_2O has made the soils sick. For example, in the rice-growing areas of Haryana and Punjab, the organic C content in the soils has declined to 0.2% from 0.5% during 20 years of intensive cropping.

Intensive cropping has already exhausted the secondary nutrients and micronutrients (Gupta and Singh, 2006). Organic farming is a practical way of addressing some major environmental problems (Mahajan *et al.*, 2007a). The integrated use of organics, inorganics and bio-fertilizers not only avoids pollution hazards of soil, water, air, crop and food but also lowers farmers' fertilizer expenses and sustains the soil's productivity (Pathak *et al.*, 2002).

Loss of Soil Productivity

The indiscriminate use of nitrogenous fertilizer without phosphate or potash has damaged the productivity of the agricultural land in the long run. Moreover, indiscriminate use of fertilizers has not only decreased the soil productivity but has also created a number of health hazards both to the soils and to human beings.

Loss of Chemical Fertility

The results from over 5,000 manurial trails in India have shown that the nutrient supplying power of many soils has declined steadily under continuous and intensive farming, and the soil fertility seems to have been stabilized at a comparatively low level. The research under LTFEs in India (Singh and Swarup, 2000) has generated the following results: Continuous application of N alone may lead to soil acidification. This has been proved in the soils of the Kandi belt of Jammu, Jammu & Kashmir, where continuous use of urea has reduced pH from 7.5 to 6.5 (Gupta *et al.*, 1992a).

Deterioration in Soil Physical Properties

The continuous use of chemical fertilizers may increase bulk density and mechanical impedance; decrease soil porosity, infiltration rate and hydraulic conductivity; and reduce water-stable aggregates and water-holding capacity of some soils (Amgain and Singh, 2001). In a silty loam soil at Palampur (Himachal Pradesh), addition of N alone for 13 years lowered available water capacity from 12.3% to 11.1% in the control, (Acharya *et al.,* 1988).

Deterioration in Biological Activity

Chemical fertilizers when applied in higher doses may prove harmful to soil life, especially when used in concentrated and water-soluble form. For example, use of fertilizers at 50% of the recommended dose enhanced the counts of bacteria, actinomycetes and fungi. On the other hand, their application at 100% and 150% of the recommended dose adversely affected the microbial population, particularly that of actinomycetes (Yaduvanshi and Gupta, 1983).

Table 1. Potential indicators or parameters that were initially evaluated for use in the soil health assessment protocol

Physical	Biological	Chemical
Texture	Root pathogen pressure assessment	Phosphorus
Bulk density	Beneficial nematode population	Nitrate nitrogen
Macro- porosity	Parasitic nematode population	Potassium
Meso- porosity	Potentially mineralizable nitrogen	pH
Micro- porosity	Cellulose decomposition rate	Magnesium
Available water capacity	Particular organic matter	Calcium
Residual porosity	Active carbon	Iron
Penetration resistance at 10kPA	Weed seed bank	Aluminum
Saturated hydraulic conductivity	Microbial respiration rate	Manganese
Dry aggregate size (<0.25mm)	Soil proteins	Zinc
Dry aggregate size (0.25- 2 mm)	Organic matter content	Copper
Dry aggregate size (2- 8mm)		Exchangeable acidity
Wet aggregate stability (0.25- 2mm)		Salinity
Wet aggregate stability (2 – 8 mm)		Sodicity
Surface hardness with penetrometer		Heavy metals
Subsurface hardness with penetrometer		
Field infltrability		

Table 2. Parameter for Assessment of Soil Health

Indicator	Relationship to Soil Health
Soil organic matter (SOM)	Soil fertility, Structure, Stability, nutrient relation ; soil erosion
Physical: Soil structure, depth of soil, infiltration and bulk density, water holding capacity	Retention and transport of water and nutrients; habitat for microbes; estimate of crop productivity potential; plow pan; water movement; porosity; workability.
Chemical: pH; Electrical conductivity; extractable N- P- K	Biological and chemical activity thresholds; plant and microbial activity threshold; plant available nutrients and potential for N and P loss.
Biological: Microbial biomass C and N; potentially mineralizable N; soil respiration	Microbial catalytic potential and repository for C and N ; Soil productivity and N supply potential ; microbial activity measure

The need of managing nutrient supply through organic sources of nutrient

The need to adopt a wider concept of nutrient use beyond but not excluding fertilizers results from several changing circumstances and developments. These are:

- The need for a more rational use of plant nutrients for optimizing crop nutrition by balanced, efficient, yield-targeted, site- and soil-specific nutrient supply.
- A shift mainly from the use of mineral fertilizers to combinations of mineral and organic fertilizers obtained on and off the farm.
- A shift from providing nutrition on the basis of individual crops to optimal use of nutrient sources on a cropping-system or crop-rotation basis.
- A shift from considering mainly direct effects of fertilization (first-year nutrient effects) to long-term direct plus residual effects. To a large extent, this is accomplished also where crop nutrition is on a cropping-system basis rather than on a single-crop basis.
- A shift from static nutrient balances to nutrient flows in nutrient cycles.
- A growing emphasis on monitoring and controlling the unwanted sideeffects of fertilization and possible adverse consequences for soil health, crop diseases and pollution of water and air.
- A shift from soil fertility management to total soil productivity management. This includes the amelioration of problem soils (acid, alkali, hardpan, etc.) and taking into account the resistance of crops against stresses such as drought, frost, excess salt concentration, toxicity and pollution.
- A shift from exploitation of soil fertility to its improvement, or at least maintenance.
- A shift from the neglect of on-farm and off-farm wastes to their effective utilization through recycling.

Organic Fertilizers

Nutrients supplied exclusively through chemical sources, though enhances yield initially, but the yields are not sustainable over the years. Even the introduction of high yielding varieties and intensive cultivation with excess and imbalanced use of chemical fertilizers and irrigation showed reduction in the soil fertility status and yield by 38 per cent of rice crop (Singh *et al.*, 2001). These causes have led to renewed interest in the use of renewable sources (organic manures/wastes) and prompted the scientists to find out an alternative agricultural system which involves the farming i.e. crop and animal husbandry in a way that harmonize rather than conflict with natural processes operating in a natural eco-system (Sharma, 2001). It can be hypothesized that the use of proper combination of locally available organic wastes which are narrow in C:N ratio and safe to apply for agricultural purposes, is as critical as that for integrated use which has an impact on growth attributes, grain and straw yield of rice (*Oryza sativa*). Among the most widely used organic manure are following-

Sewage Sludge

Latare *et al.,* (2014) reported that the soil application of sewage sludge in crop production offers an alternative technique for its disposal and management. The study was done to evaluate the effect of sewage sludge on yield of rice, soil fertility and heavy metals accumulation in grain and straw in a glass house. The residual effect of sludge application was evaluated in subsequent wheat crop in the sequence. Five doses of sludge i.e., 0,10, 20, 30 and 40 t ha^{-1}were applied to rice and their effects were compared with the recommended dose of fertilizers i.e., 120, 60 and 60 kg N, $P_2O_5$and K_2O ha^{-1}, respectively. There was significant increase in straw and grain yields of both the crops with application of sludge. The grain yield of rice increased 45% at 40 t ha^{-1}sludge application over no sludge. The residual effect on wheat yield was more pro-nounced. Increase in available nutrients content of soil was also recorded with increasing levels of sludge application after harvest of rice and wheat crops.

Vermicompost

Dastmozd *et al.,* (2015) reported that sustainability in food production and sustainable agricultural systems depends greatly on reusing inputs in the production system, thereby increasing the efficiency of inputs per unit of inputs. Since the global approach to plant growth is based on the use of sustainable agricultural systems and the application of management practices such as the use of vermicompost fertilizer to enhance the qualitative and quantitative yield of crops, the study explored the effect of vermicompost fertilizer as a biological agent compared with fertilizers on yield and yield components of wheat. Ravi and Srivastava (1997) reported that combined application of vermicompost and inorganic fertilizers recorded significantly higher plant height, effective tillers hill^{-1}, grain and straw yield of rice, compared to application of inorganic fertilizer alone.

Sesbania

Bajpai *et al.,* (2006) reported that the long-term permanent plot field experiment was conducted from 1991-92 to 2002-03 to develop suitable integrated nutrient supply system for rice-wheat cropping system. The study was aimed to find out the effect of organic sources of nitrogen integrated with chemical sources on rice and their residual effect on succeeding wheat in rice-wheat cropping system at the Raipur Inceptisol. The initial fertility status of the soil was 234 kg N, 11.5 kg P and 280 kg K ha^{-1}, respectively. Initial bulk density and infiltration rate of experimental field were 1.51 Mg m-3 and 1.63 cm hr^{-1}, respectively. Over the 12 years of study period, highest rice yield was obtained when 50% of nitrogen was supplied through green manuring (GM). When 50% N was supplied through farmyard manure (FYM), it produced rice yield at par with the treatment where, 100% NPK had been applied through chemical fertilizers. Significant residual effect of GM was observed on the following wheat yield during rabi. Incorporation of organic sources considerably improved the soil properties such as decrease in bulk density and increase in infiltration rate and available NPK status of the soil.

Sustainable Plant Nutrient Management

Integrated approach of nutrient supply by chemical side provided a good substrate for the growth of micro- fertilizers along with organic manures and biofertilzers organisms and maintain a favourable nutrient supply is gaining importance as this system not only reduces environment and improve soil physical properties. Use of the use of inorganic fertilizers but is also provides a biofertilizers with organic manures may prove a viable environment-friendly approach. In most long-term experiments, a combination of mineral fertilizers and farmyard manure has generally given the best crop yield and soil quality (Wang *et al.*, 2004; Chalk *et al.*, 2003). Singh *et al.,* (1983) reported that application of poultry manure alone was about 1.5 times more effective than compost alone in increasing yields of rice and maize as well as building up more available Zn in soil than did compost alone. Sharma and Saxena (1985) indicated that incorporation of poultry manure or FYM in to the soil increased maize yields besides improving soil P indices.

The Integrated Nutrient Management (INM) is the maintenance of soil fertility for sustaining increased crop productivity through optimizing all possible sources, organic and inorganic, of plant nutrients required for crop growth and quality in an integrated manner, appropriate to each cropping system and farming situation in its ecological, social and economic possibilities (Roy, 1986). The basic concept underlying the principles of INM is to integrate all sources of plant nutrients and also all improved crop production technologies into a productive agricultural system (Roy, 1986). In other words, integrated nutrient management aimed to maintain the soil fertility and plant nutrient supply to an optimum level for sustaining the desired crop productivity through optimization of the benefits from all possible sources of plant nutrients in an integrated manner. Therefore, it is a holistic approach, where we first know what exactly is required by the plant for an optimum level of production, in what different forms these nutrients should be applied to soil and at what different timings is the best possible method, and how best these forms should be integrated to obtain the highest productive efficiency on the economically acceptable limits in an environment friendly manner (Chundawat, 2001). One characteristic of the INM is that the fertilizer recommendation should take into account the cropping system as a whole rather than individual crop in the system. Similarly, the nitrogen contribution of legume crops in the cropping system will have to be considered.

Customized Fertilizer

The ‘Customized Fertilizer’, made up of mixing Nitrogen, Phosphorus, Potassium, Sulphur and Zinc has been tested for enhancing wheat yield. Customized fertilizers are unique and ready to use granulated fertilizers, formulated on sound scientific plant nutrition principles integrated with soil information, extensive laboratory studies and evaluated through field research (Rakshit et al., 2012). The Central Fertilizer Committee has included customized fertilizers in the Fertilizer (Control) Order (FCO) 1985, as a new category of fertilizers that are area/soil/crop specific. . Customized fertilizers are multi- nutrient carriers facilitating the application of the complete range of plant nutrients in right proportion to suit the specific requirements of a crop during its stages of growth. Soil fertility status, climate, and cropping pattern in a region pave the way for the development of customized fertilizer formulations. Customized fertilizers are unique and ready to use granulated fertilizers, formulated on sound scientific plant nutrition principles integrated with soil information, extensive laboratory studies and evaluated through field research. Customized fertilizers development process is complex but, the end very promising. It optimizes the nutrient use for quality produce, high farm productivity and profitability.

Conclusion

It is concluded that application of full dose of inorganic fertilizer alone (N_{150}, P_{60}, K_{60}) or 25% less of inorganic in combination with organic manners i.e. sewage sludge or vermicompost or sesbania was adequate for optimum yield of plant crop. Furthermore, it was revealed that when crops are grown following full doses of inorganic fertilizer, N, P and K doses may be reduced by 25% from inorganic fertilizer in subsequent first and second rice crops. Alternatively when plant crops are grown with 25% less of inorganic fertilizer along with organic manners, organic manures may be reduced by 50%, i.e. in subsequent first and second rice crop. Therefore, to maintain soil fertility as well as higher yield of plant and rice crop, integration of inorganic fertilizer, and organic manure would be beneficial.

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