An overview of recent approaches in enhancing sesame productivity in coastal saline soils through micronutrients fortified organic manures

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Abstract

Micronutrient deficiencies in soils limit crop yields and nutritional quality, which in turn negatively affect human health, especially in most of the salt affected soils. Majority of the coastal coarse textured soils have multiple micronutrient deficiencies which makes soils non responsive to NPK fertilization. The impact of agronomic bio-fortification largely depends on the bioavailability of micronutrients throughout the entire pathway/ entire crop growth periods from soil to plant. In majority of the coastal area next to groundnut, sesame is the dominant crop cultivated in nutrient poverished coastal sandy/sandy loam soils. However, the yield obtained on the coastal regions are very low and far below the national average yield. Nutritional imbalance in plants due to inadequate availability of both macro and micronutrients in coastal saline soil was established as the prime reason for low yield potential of oilseed crops. To cutoff the saline stress and enhancing the crop yield certain nutrient management strategies need to be incorporated along with blanket recommendations. With this view, we have collected recent literatures form various sources and detailed the importance of organic manures, micronutrients, and certain important sources on productivity crops especially sesame and other oilseed crops and also to mitigate saline stress.

**Keywords:** Coastal saline soils, Fortified organic manures, Micronutrients, Sesame

1. **Introduction**

The Indian peninsular region has 8,129 km long coastline. The total geographical coastal area of the country is as high as 10.78 M ha. Tamil Nadu alone occupies 6,80,622 ha of coastal area constituting 26.8 per cent of the total area of the coastal districts. In India, coastal region covers a long strip, over the eastern and western border are severely degraded and, pose serious problems for agricultural production (Ray *et al*., 2014). Coastal saline soils cover an area of about 932.2 M ha in the world, of which 56 M ha comprises secondary salinized irrigated lands (Quadir *et al*., 2014). In the world about 833 M ha are salt affected soils. In India, around 6.72 M ha of salt affected whereas, 2.95 M ha is saline and 3.77 M ha is sodic soil. In Tamil Nadu nearly 2.04 L ha are coastal saline soil (Mandal *et al*., 2018). The soil salinization has tremendous environmental, ecological, and social impacts in terms of shrinkage of agricultural lands, agricultural productivity, unstable livelihood security and poor quality of life. The net primary productivity (NPP) of saline soils is low, due to toxic concentration of salts and deficiencies of essential nutrients especially micronutrients (Lal, 2009). High salt concentration and nutrient deficiencies especially micronutrients are the main factors of low crop yield in coastal saline soil (Arulrajasekaran *et al*., 2021). In this context, almost the entire coastal tracts of soil as well as water are suffer from salinity, sodicity and seawater intrusion, which resulted in the low productivity of crops. The coastal ecosystem provides livelihood to several million people and then contribute to the national economy to a significant extent. The coastal agriculture faces a host of difficult problems related to seawater, poor quality water, cyclones and flood. The low lying agriculture lands frequently suffer from severe drainage and soil salinity problem. Soil and water salinity hampers crop production in the coastal ecosystem to greater extent.

Micronutrient deficiencies in soils limit crop yields and nutritional quality, which in turn negatively affect human health, especially in most of the salt affected soils in coastal regions of Tamil Nadu. Majority of the coastal coarse textured soils have multiple micronutrient deficiencies which makes soils non responsive to NPK fertilization. Poor crop yields in combination with diets that are mainly based   
on staple crops, causes widespread micronutrient deficiencies among the population. A suggested strategy to alleviate micronutrient deficiencies in this region is agronomic bio-fortification, particularly of staple foods. The impact of agronomic bio-fortification largely depends on the bioavailability of micronutrients throughout the entire pathway/ entire crop growth periods from soil to plant, from plant to food and uptake by the human body. Factors that determine bioavailability are mainly soil conditions, crop variety, food processing, concentration of micronutrient inhibitors or enhancers in food, dietary intake, the forms of micronutrients in food, interactions among nutrients, and physiological condition of individuals. These effects of fortified organic manure with micronutrients like zinc, iron and manganese to maximizing the potentiality of bio-fortification of micronutrients and yield, nutritional quality of sesame crops and human health.

During the era of green revolution, introduction of high-yielding varieties, extension of irrigated areas, use of high analytical value of NPK fertilizers and increase in cropping intensity, boosted the production in most of cases, propelled India towards self-sufficiency in food production. In the process, relative contribution of organic manures as a source of plant nutrients *vis-a-vis* chemical fertilizers declined substantially (Bhadu *et al*. 2017). One way of replenishing nutrients in the arable lands is to recycle nutrients through application of organic material such as litter, crop residues, and manures. Organic manures, especially farmyard manure, have a significant role for maintaining and improving the physical, chemical and biological properties of soils. Organic materials play a critical role in sustainability in the coastal regions. Despite this importance, there is little predictive understanding for the management of organic inputs in coastal agro ecosystems. It is now widely recognized that soil organic matter plays an important role in soil physical, chemical (pH, base saturation, salinity and CEC changes) and biological properties. Organic amendments, such as FYM and composted agro industrial bi-products are known to improve soil physical properties. Organic matter is an important soil constituent influencing a number of constraints linked with crop productivity. The loss of soil fertility, in many developing countries, due to continuous nutrient depletion by crops without adequate replenishment poses an immediate threat to food and environmental security. Intensive cropping and tillage system have led to substantial decreases in soil organic matter levels of much prime land in the world. This decrease in soil organic matter levels seems to be associated with the decline in soil productivity. Hence, the application of organics is essential for maintaining soil fertility. Use of fortified organic manures is one of the technologies to enhance the nutrient use efficiency as well as decrease the nutrient losses (Aswini *et al*. 2015). The aim of enrichment of organic manures is to minimize excess use of fertilizers for optimum yield and quality of sesame crops without harming soil and environment health by the application of micronutrients fortified organic manures like plant nutrient enriched FYM.

In majority of the coastal area next to groundnut, sesame is the dominant crop cultivated in nutrient poverished coastal sandy/sandy loam soils. Sesame is the most important oil seed crop of India as well. A glimpse of the sesame crops in India’s position *vis-à-vis* other countries in the world shows that it occupies 35.2 per cent of area and 28.6 per cent production. India ranks first in area (29%), production (26%) and export (40%) of sesame in the world. Sesame seeds are rich source of protein, minerals, edible oil and bio-medicine. Sesame oil has excellent nutritional, medicinal, cosmetic and cooking qualities for which it is known as **“The Queen of Oils”**. Due to the presence of potent antioxidants, sesame seeds are called as “the seeds of immortality”. In majority of the coastal area, oilseed crops are cultivated in nutrient impoverished soils. Among the oilseeds, sesame (*Sesamum indicum* L.) is one of the most important oilseed crop grown in coastal soils. India is the highest producer of sesame in the world which occupies an area of 17.6 lakh ha with a production of 7.85 lakh tones, however the average yield is very low (446 kg ha-1) as compared to national average yield of around 700-800 kg ha-1 (Elayaraja *et al*., 2019). In Tamil Nadu, the area under cultivation of sesame is 1.12 lakh hectares with a production of about 16,000 tonnes and average productivity is 589 kg ha-1 (Kaul *et al.,* 2020). The short duration, drought tolerant, low water and nutrient requirement of sesame attracts many farmers in these regions to cultivate this crop. However, the yield obtained on the coastal regions are very low and far below the national average yield. Nutritional imbalance in plants due to inadequate availability of both macro and micronutrients in coastal saline soil was established as the prime reason for low yield potential of oilseed crops.

Further India’s per capita consumption of oil and fat is continuously increasing, so, there is an urgent need to increase sesame production. India needs 38.63 Mt of oil seeds to feed 1.75 billion populations by 2050 (Jahan *et al.,* 2019). This Herculean task is to be achieved though steep increase in the productivity of different oil seed crops using improved technology and increasing cropping intensity. Increasing area under cultivation is limited due to increasing demand of land for the burgeoning population. The other option is to increase the productivity of crop using scientific management practices including integrated nutrient management. Under such situation, the coastal area offers a greater scope to increase production where at present the productivity is low. Considering the inherent poor soil fertility, poor yield and economic condition of the coastal farmers, it is an imperative need to develop technology for the management of micronutrients and recycling of locally available organic manures to achieve sustainable soil fertility and increase yield of sesame.

In India nearly 47% of the soils are deficient in zinc and 5 per cent in manganese. In Tamilnadu, zinc and manganese deficiencies are about 58.4 and 6.0 per cent, respectively. The deficiencies are most common in coastal areas of coarse textured, high pH soils wherein organic matter content is low. These soils require micronutrient fertilization along with organic manures to achieve sustainable productivity. In addition, the light texture coastal soils are also well known for the deficiency of micronutrients like zinc and manganese. In sesame production and improving the quality, the micronutrients play a vital role (Shirazy *et al.,* 2015 and Seervi *et al.,* 2018). Micronutrient is also recognized as a key element for protein synthesis, biological nitrogen fixation and also plays an important role in various enzymatic activities in the growth and development of plants (Elayaraja, 2008 and Chaurasia *et al*., 2009). Several earlier works has emphasized the need for application of micronutrients for increasing the growth, yield and quality of sesame (Javia *et al.,* 2010 ; Kurt *et al.,* 2018 and Jose *et al.,* 2021).

Pink pigmented facultative methylotrophic bacteria (PPFM), ubiquitous in nature and frequently reported on various plant species, are a substantial part of the aerobic, heterotrophic microflora of the surfaces of young leaves (Meena *et al.,* 2012). They are capable of growing on C1 compounds such as formate, formaldehyde and methanol in addition to C2-C4 compounds. Moreover, they are able to produce plant growth regulators such as cytokinins and auxins, which affect plant growth and different physiological processes. The PPFM can also induce systemic resistance against diseases and degrade a widely range of highly toxic compounds and tolerate heavy metals (Iguchi *et al*, 2015 and Gawad *et al*., 2015). Excessive use of chemical fertilizers to increase production from available land has resulted in deterioration of soil quality. To prevent further soil deterioration, the use of pink pigmented facultative methylotrophic bacteria (PPFM) that have the ability to colonize different habitats, including soil, sediment, water and both epiphytes and endophytes as host plants, has been suggested for sustainable agriculture. Methylotrophic bacteria are known to play a significant role in the bio-geochemical cycle in soil ecosystems, ultimately fortifying plants and sustaining agriculture. Foliar spraying PPFM is also said to influence the crop growth by producing plant growth regulators like zeatin and related cytokinins and auxins. Further, reduces the flower drop and improves the capsule formation and seed setting percentage. Increased drought tolerance and reduced flower drop can be achieved in oil seed crops by foliar spray of PPFM.

Soil fertility is the most limiting factor for crop production in coastal saline soil. Coarse textured soils have several soil problems *viz.,* light texture, poor exchange property, and nutrient and water retention capacity, low status of soil organic carbon and deficiency of both macro and micronutrients. These problems severely affect the productivity of oilseeds especially in sesame in this region. Even the applied NPK nutrients are leached to the sub surface soil. Coastal salt affected soils are most commonly suffered due to zinc and manganese deficiency. Boron, iron and copper are also deficient in some locations. The zinc plays a vital role to improve production and quality of sesame. Zinc is also recognized as a key element for protein synthesis, biological nitrogen fixation and also plays an important role in various enzymatic activities in the growth and development of plants. Manganese play a vital role in photosynthesis reaction, nitrogen metabolism and to form other compounds required for plant metabolism enzyme activation and root growth (Mortvedt *et al*., 1999 and Shehu, 2014). It is now established that micronutrient deficiency is the prime factor responsible for that low productivity of sesame in coastal areas. Among the micronutrients fertilizers, ZnSO4 and MnSO4 is most common and widely used source of Zn and Mn fertilizer by the farmers, the reasons being, easy water solubility and high Zn content (20-25%). Moreover, it is easily leachable in coastal sandy/sandy loam soils due to poor organic matter as well as highly leaching losses which resulted in low availability or use efficiency of Zn in crop plants. In this context, now a day’s fortified organic manures with micronutrients is becoming an established nutrient supplementation technique in crop production to increase the sesame yield and quality of crops. In addition to that some part of water soluble Zn may be converted to insoluble ZnCO3 and Zn (OH)2. However, other than zinc sources like ZnEDTA is costlier than zinc and manganese fortified composted coirpith and FYM (ZnECCP/ZnEFYM) therefore it is not affordable to farmers and increase the cost of production. Hence, inclusion of recommended dose of NPK fertilizer, micronutrient fertilizer like zinc along with Zn or Mn fortified manures techniques becomes an imperative need to improve the yield of oil seed production. It is more vivid that applications of NPK, micronutrients along with fortified organic manures for sustain soil health and crop productivity in coastal saline soil. Hence, in the present investigation, an attempt has been made to study the effect of zinc and manganese fertilization along with recommended dose of NPK and fortified organic manures to increase the productivity and quality of sesame as well as to improve the soil fertility status for sustainable soil health in coastal saline soil.

The present review was carried out for finding pros and cons of sesame productivity in coastal saline soils using micronutrients fortified organic manures and improving the soil fertility. The literature pertaining to the influence of micronutrient fertilization of coastal saline soil with recommended dose of NPK and bio-fertilizer along with fortified organic manures have multidimensional effect in improving the soil fertility and sustaining sesame productivity.

2. Organic manures in crop production

Use of organic manures to meet nutrient requirement of crop would be an inevitable practice in the years to come sustainable agriculture, since organic manures generally improve the physical, chemical and biological properties along with conserving and improving the moisture and nutrient holding capacity of soil and there by resulting in enhanced nutrient uptake and quality of crop produce (Kadam *et al.,* 2000). Incorporation of organic manures along with chemical fertilizers has been found to be effective for sustainable oilseed crop production. Combined application of organic manure and inorganic fertilizers sustained productivity by improving soil physical conditions and also reduces the cost of inorganic fertilizers needs (Kachot *et al.,* 2001). Kavitha and Swarajya Lakshmi (2002) stated that there was a strong need to adopt INM by judicious combination of organic manure, inorganic fertilizers and biofertilizers to improve soil health and productivity. Hanumanthappa and Shivaraj (2003) have reported that addition of 100 per cent recommended dose of NPK along with composted coirpith @ 3.8 t ha-1 recorded the highest N, P and K uptake by sesame as compared to control. Purushottam (2005) found that application of FYM along with recommended dose of fertilizer registered the highest growth attributes, yield attributes and seed yield of sesame. Balaguravaiah *et al.* (2005) indicated that application of half recommended dose of NPK along with FYM @ 4 t ha-1 increased the organic carbon, available N, P and K in soil as compared to recommended dose of fertilizer and control. Varalakshmi *et al.* (2005) observed that the application of 100 per cent recommended NPK + FYM @ 7.5 t ha-1 resulted in higher organic carbon, available N, P2O5 and K2O in the post harvest soil.Mann *et al.* (2006) indicated that application of FYM @ 10 t ha-1 along with 100% NPK fertilizers increase the organic carbon (0.8%) and availability of NPK in *Typic Ustochrept.* Chalwade *et al.* (2006a) reported that coirpith can be used as soil amendment under varied soil conditions, for improving the physical, chemical and biological properties of soil. It is a good source of mulch for increasing the water holding capacity to sandy loam soil.

Agasimani *et al.* (2007) concluded that combined application of poultry manure along with 100 per cent recommended dose of fertilizer recorded the higher organic carbon and available N, P and K in the soil. Complementary use of available renewable sources of plant nutrients in the form of organic manures in maintaining a proper balance of soil health for sustainable crop production (El-Habbasha *et al.,* 2007, Elayaraja, 2008 and Yadav *et al*., 2009) was already established.

Deshumkh *et al.* (2010) stated that application of recommended dose of fertilizers (60:40:20 NPK kg ha-1) + FYM @ 25 t ha-1 + vermicompost @ 5.0 t ha-1 and seed treatment with Azospirillum and phosphorus solubilizing bacteria (PSB) recorded the highest growth characters *viz.*, plant height, number of branches plant-1 and yield attributes *viz*., number of capsules plant-1 and 1000 seed weight of sesame. Vijayakumari and Hiranmai (2012) noticed that, the application of vermicompost @ 5 t ha-1 along with 100 per cent recommended dose of NPK (35:23:23 kg ha-1 of NPK)recorded the higher shoot length, dry matter production and yield of sesame as compared to control. Verma *et al.* (2012) organic manure improves the overall physical characteristics of the soil organic matter together with major and micronutrients and prevent physical compaction of soil, improves soil aeration, and nutrient leaching. Khan *et al*. (2014) indicated that the application of biocompost @ 6 t ha-1 in sodic soil enhanced the available nutrients contents in soil and thus increasing the overall soil fertility status. Integrated use of organic and inorganic fertilizers in a balanced proportion for sustainable production of sesame was emphasized by earlier research workers Singaravel *et al*. (2016); Elayaraja andSingaravel (2017) and Oloniruha *et al*. (2021). Raghavendra *et al*. (2020) revealed that yield and yield components of sunflower were influenced favorably by soil application of ZnSO4 @ 10 kg ha-1 + foliar spray FeSO4 @ 0.5% along with the RDF and FYM @ 8 t ha-1 recorded significantly highest grain yield (2268 kg/ha), oil content (41.3%) and test weight (5.47 g) of sunflower, respectively as compared to control. Lokhande *et al*. (2020) revealed that among the different organic manures applied, the application of 75% N through (Urea) + 25% N (Poultry manure) was found to beneficial in increasing growth attributes *viz.,* higher plant height (81.67 cm) number of branches plant-1 (4.2) number of functional leaves (79.93), leaf area (10.68 dSm-2) and dry matter plant-1 (37 g). The yield attributes *viz.,* number of capsule plant-1 (53.80), seed yield plant-1 (8.95 g) capsule yield plant-1 (45.21 g), seed yield (516 kg ha-1) and test weight (3.9 g) of sesame, respectively.

1. Composted coirpith in crop production

Selvi (2002) concluded that coirpith along with NPK fertilizers application significantly increased the nutrients status of the soil. Results state that composted coirpith application @ 15 t ha-1 significantly improved organic carbon content in soil, besides yield increase in soybean. Hanumanthappa and Shivaraj (2003) have reported that addition of 100 per cent recommended dose of NPK along with composted coirpith   
@ 12.5 t ha-1 recorded the highest N, P and K uptake by sesame as compared to control. Chalwade *et al.* (2006b) reported that application of coirpith can be used as soil amendment under varied soil condition, for improving the physical, chemical and biological properties of soil and also it is a good source of mulch for increasing the water holding capacity to sandy and sandy loam soil. Elayaraja (2008) reported that in a coastal sandy soil, improved organic carbon, nutrient availability (N, P, K, Zn, B, Fe and Cu) and enzymatic activity (urease, phosphatase and dehydrogenase) were obtained with 150 per cent recommended dose of NPK + ZnSO4 @ 30 kg ha-1 + borax @ 15 kg ha-1 along with composted coirpith @ 12.5 t ha-1. A significant reduction of pH and EC content of the soil was also recorded.Hossain *et al*. (2012a) indicated that application of coirpith @ 20 t ha-1 recorded the highest fruit yield of 34.03 t ha-1 as compared to 15.74 t ha-1 in control. According to Taalab *et al.* (2013) the soil fertility status like organic carbon, available NPK and micronutrients was higher with green manure or FYM or composted coirpith along with NPK fertilizer than with NPK fertilizer application alone. Coirpith is a highly cellulosic material, has attractive features like improvement of soil physico-chemical properties, soil conditioning moisture retentively and readily nutrient availability to the soil. Coirpith application helped in slow release of applied fertilizers as it acted as a matrix in soil and improved soil physical properties like bulk density, cation exchange capacity and infiltration rate (Ganesh and Suresh Kumar, 2016).

Arulrajasekaran *et al*. (2021) conducted a laboratory incubation experiment and results showed that beneficial influence of the treatment NPK + 75% Zn and Fe + bioactive compound fortified organic manure @ 5 t ha-1 reduces the pH, EC and increases the micronutrient DTPA-Zn (0.90 mg kg-1) and DTPA-Fe (5.77 mg kg-1) availability in soil.Elayaraja and Jawahar (2021) found that the combined application of 125% NPK + micronutrient (Zn+Mn) enriched composted coir pith (MNECCP) @ 5 t ha-1 was superior in growth and yield characters *viz.,* plant height (128.65 cm), number of branches plant-1 (9.97), dry matter production (2059 kg ha-1), number of seed capsule-1 (58.17), 1000 seeds weight (3.43 g), seed and stalk yield (739 kg ha-1, 1666 kg ha-1) of sesame, respectively as compared to control.An overall improvement in the physical (decreased bulk density, particle density and increased water holding capacity), chemical (decreased pH, EC and increased organic carbon, available N, P, K and micronutrients) and biological (bacteria, fungi, actinomycetes and urease, phosphatase and dehydrogenease activity) properties of soil was noticed with recommended dose of NPK + biofertilizer and composted coirpith along with micronutrients like zinc, boron and manganese application under coastal saline soil condition (Singaravel *et al*., 2006; Elayaraja, 2008; Beema, 2016; Sivaranjini, 2017; Karthika, 2019 and Vigneshwarraj, 2020).

4. Fortified organic manures in crop production

Basavaraj and Manjunthaiah (2003) found that the combined application of   
P-enriched organic manure along with 100% RDF-P had significant effect on grain yield of maize, which accounted 27.50 per cent increase in yield over control.

Ahmad *et al*. (2007) revealed that, the application of rock phosphate (RP) fortified with FYM + PSB had significantly highest wheat yield among all the treatments however, it was statistically at par with RP + PM + PSB. Rock phosphate (RP) fortified with FYM + PSB had recorded 16.49% higher yield over SSP alone. Yield attributes like number of spikes, number grains per spike, 100 grain weight were found maximum with RP + FYM + PSB being statistically at par with all fortified treatments except RP alone and RP+ FYM. Application of compost fortified with N and L-TRP in the presence of 50% supplementary dose of N fertilizer significantly increased the fresh biomass (11.8%), cob weight (12.6%) and grain yield (13.6%) compared to full dose of N fertilizer. Similarly, application of fortified compost plus 50% N had significant increasing effect on root weight (15.7% more than the full dose of N fertilizer) of maize plants. In general, N plus L-TRP fortified compost gave better performance than the application of N fortified compost.

Meena *et al*. (2008) reported that, application of Zn and Fe fortified FYM improves the average mustard seed yield by 20 per cent over control whereas it was 11 per cent over straight Zn and Fe application. The Zn and Fe fortified FYM enhanced uptake of N, S and micronutrients by mustard, and improved oil and protein content of mustard seed. The yield of subsequent sorghum (fodder) increased by   
11 per cent due to residual effect of FYM over control. A significant increase in yield of sesame was noticed in the treatments which received Zn fortified compost @ 15 kg ha-1 which recorded grain yield (54.06 q ha-1) and straw yield (78.01 q ha-1) further 10 kg ha-1 of Zn fortified compost registered significant grain yield (53.96 q ha-1) straw yield (78.90 q ha-1) and it was on par with farmers package of practice were noticed by Veeranagappa *et al*. (2010). Sridevi *et al*. (2010) studied that to find out the effect of zinc- fortified organic manures. The treatments were NPK alone, NPK +200 kg FYM ha-1 without enrichment, NPK + 200 kg FYM ha-1 fortified with different levels of Zn (1.25, 2.50 and 5.0 kg Zn ha-1), NPK + cow dung without fortified, NPK + 200 kg cow dung fortified with different levels of Zn. The result of the field experiment revealed that recommended dose of NPK + 200 kg ha-1 FYM fortified with 5.0 kg zinc increased the grain (5430 kg ha-1) and straw (7075 kg ha-1) yields which was due to increased availability of zinc in soil.Ahmad *et al*. (2012) concluded that application of ZnSO4 + fortified FYM proved better rather than application of ZnSO4 or Zn-EDTA alone. The results indicated the positive role of organic matter in increasing grain yield and grain Zn concentration on soils which affected with salts and depleted in organic matter. The increase in plant growth and Zn concentration was higher when plants were grown with Zn fortified FYM compared to ZnSO4 or Zn-EDTA application alone. The maximum Zn concentration in rice grains (13.9 mg kg−1) and straw (19.1 mg kg−1) were obtained by the application of ZnSO4 + fortified FYM.

Mali *et al*. (2015) observed that the maximum plant height (206.73 cm),   
dry matter production (164.67 g plant), average cob length (16.87 cm), number of grains cob-1 (391.00 grain cob), cob weight (134.67 g) and test weight (197.0 g) were recorded under application of 25% RDP through Phosphorus Rich Compost + vermiculture + PSB + 75% RDP through DAP. The maximum grain yield (3.93 t ha-1), stover yield (5.74 t ha-1), net return (38337 Rs ha-1) and B:C ratio (2.19) were recorded under application of 25% RDP through PRC + vermiculture + PSB + 75% RDP through DAP and lowest grain yield (1.89 t ha-1), stover yield (3.14 t ha-1), net return (14611 Rs ha-1) and B:C ratio (1.14) were noted in control where phosphorus rich compost was not applied. Maximum yield response (107.5%) was recorded with 25% RDP through PRC + vermiculture + PSB + 75% RDP through DAP followed by 25% RDP through PRC + PSB + 75% RDP through DAP (95.7%). Ashwini *et al*. (2016) found that, among the methods of application,   
spot application of fortified manure recorded significantly higher 1000 grain weight (24.24 g) and grain yield (54.03 q ha-1) due to timely available of nutrients. Interaction of spot application of fortified manure with 125:62.5:62.5 kg NPK ha-1 has registered higher grain yield (60.58 q ha-1) and filled grains panicle-1 (128.75). While, higher 1000 grain weight (25.80 g) was recorded in spot application of fortified manure with 100:50:50 NPK kg ha-1. Patel *et al*. (2016) indicated that, to find out the effect of Fe and Zn fortified with farm yard manure on growth and yield, quality and uptake of nutrients for cumin. Enrichment of Fe or Zn or both with FYM increased not only seed yield but net income and BCR also. Combined application of Fe and Zn found better than sole application of Fe or Zn. Moreover, enrichment of Fe and Zn with FYM not only reduced the 50 per cent requirement of micronutrient but also increase the yield (577 kg ha-1). An application of RDF along with 1.0 t ha-1 FYM fortified with 1.5 kg Fe and 0.75 kg Zn ha-1 (T8) registered significantly higher uptake of Fe (64.70 g ha-1) and Zn (24.60 g ha-1) by seed, respectively.

Regar and Yadav (2017) found that application of PGPR and Zn @ 5.0 kg ha-1 fortified FYM along with 60 kg P2O5 ha-1 resulted in markedly higher plant height (109.07 cm), grain yield (59.62 q ha-1), straw yield (79.94 q ha-1) and biological yield (139.56 q ha-1) but showed at par result with PGPR and Zn @ 2.5 kg ha-1 fortified FYM applied in conjunction with 40 kg P2O5 ha-1.

4.1. Effect of fortified organic manures on soil fertility

Improvement in the nutrient uptake with the use of fortified FYM either alone or in conjunction with fertilizer was observed by Debele *et al*. (2000). Senthilkumar *et al*. (2004) indicated that the soil organic carbon (SOC) declined while there was marginal increase in available N due to fortified FYM. Further, addition of farmyard manure   
@ 12.5 t ha-1 along with Zn solubilizing bacteria stood superior by registering highest values for available of N, P and K content in the soil. The DTPA - Zn content of the soil though evidenced significant variation for the application of FYM, FYM + ZSB, Zn + Fe on an overall basis the actual values did not exceed the deficiency level. Ahmad *et al*. (2007) reported significant improvement in N, P and K contents of maize plant in response to application of N and L-TRP fortified compost (enrichment of compost with N and L-tryptophan) supplemented with 50% N fertilizer. Maximum increases (10.1% N, 11.9% P and 7.5% K) were found in response to combined application of fortified compost and N fertilizer compared to sole application of full dose of N fertilizer. The effect of N fortified (without L-TRP) compost + 50% N was statistically similar to that observed in case of full dose of N fertilizer alone. Nitrogen, phosphorus, potassium and zinc uptake significantly differed among the treatments. Recommended NPK + 200 kg ha-1 FYM fortified either with 5.0 or 2.5 kg Zn ha-1 was superior in recording higher nitrogen uptake than control, but on par with each other treatments and showed statistical parlance among themselves (Sridevi *et al.,* 2010).Use of imbalanced chemical fertilizers without proper organic amendments could have reduced the fertility status of soil that necessitates the use of IPNS in coastal salt affected soils. Combining organic amendments with reduced chemical fertilizer is a promising approach to develop suitable fertilization strategies, which may faster agricultural sustainability by promoting soil microbial biomass and enzyme activity (Mandal *et al.,* 2007 and Mohanty *et al.,* 2015). Singaravel *et al*. (2016) indicated that the continuous application of organic inputs with reduced chemical fertilizers facilitated in accumulation of organic carbon, which in turn had significant incremental effect on the soil microbial biomass and soil enzyme activities in soil. In particular, use of fortified compost with low amount of chemical fertilizers improved the soil physical, chemical and biological properties, which were reflected in increased the yield of crops.

5. Pink pigmented facultative methylotrophic bacteria (PPFM) in crop production

Methylotrophs on plants surfaces can be major sink of volatile organic compounds (VOCs) such as methanol and other C1-VOCs, thus improving air quality (Fall, 1994). According to Schaefer and Oremland, (1999) reported that some facultative methylotrophs are reported oxidize methylbrimide, while a few methanotrophs degrade volatile trichloro acetic acid (TCE). In their intimate relationship with host plants, the significance of these bacteria is apparent. These have been extensive studies on methylotrophs and their ability to promote plant growth and development by co-inoculation with a different group of bacteria in pot and field conditions. Recently, higher yields of rice and tomatoes have been reported following rhizospheric bio-inoculations (Methylobacterium suomiense CBMB120) of crops (Poonguzhali *et al.*, 2008). Methylotrophic bacteria utilize single carbon (C1) compounds for energy and assimilation and are an important component of the global carbon cycle. One group of methylotrophs, pink-pigmented facultative methylotrophic bacteria (PPFMs), is distinguished based on their formation of pink to red colonies on selective isolation media. Classified within the genus Methylobacterium, PPFMs are facultative methylotrophs, using both single and multi carbon compounds. Pink-pigmented facultative methylotrophic bacteria (PPFMs) are associated with the roots, leaves and seeds of most terrestrial plants and utilize C1 compounds such as methanol generated by growing plants during cell division. PPFMs have been well studied in agricultural system due to their importance in crop seed germination, yield, pathogen resistance and drought stress tolerance. There are two mechanisms by which PPFMs can positively affect plants, particularly in dry climates. First, PPFMs excrete auxins and cytokinins, plant growth hormones that influence germination and root growth and play critical roles in a plant’s response to water /salt stress. In dry conditions, plants that send their roots deep quickly after germination may gain a competitive advantage over more shallowly rooted species. Second, PPFMs exclude osmoprotectants (sugars and alcohols) on the surface of host plants. This matrix may help protect the plants from desiccation and high temperature (Irvine *et al*., 2012).

Excessive use of chemical fertilizers to increase the production from available land has resulted in deterioration of soil quality. To prevent further soil deterioration, the use of pink pigmented facultative methylotrophic bacteria that have the ability to colonize different habitats, including soil, sediment, water and both epiphytes and endophytes as host plants, has been suggested for INM or IPNS as well as sustainable agriculture. As a result of a green revolution, there have been notable increases in agricultural production with the use of technology that released crop cultivation from cultural, religious, and environmental constraints. Continuous biological and chemical research and exploitation have increased our agricultural knowledge. Chemical fertilizers, an essential component of modern agriculture, supply nutrients required for optimal crop improvement that are not available in the soil and or from other available organic sources. The use of chemical fertilizer has an “environmental footprint”. It diminishes crop yield, destroys the soil nutrient balance, leads to poor soil quality in terms of physiochemical properties, and gives rise to a variety of plant diseases. The use of chemical fertilizers not only costly, but also hazardous for both the environment and humans. In addition, manufacturing of such fertilizers deplete non renewable natural resources (Dubey *et al.,* 2012).

Methylotrophs are associated with either the plant Rhizosphere or phyllosphere or both and show no pathogenic activity. In seed coating or seed inoculums, methylotrophs can be used to enhance seed germination (Meena *et al.,* 2012). Thus, a biological substitute for chemical fertilizers that will efficiently provide nitrogen and phosphorus to plants and prevent the depletion of soil fertility and soil quality is essential.   
Bio-inoculants have been used as a commercial alternative to chemical fertilizers to reduce environmental effects and diseases and promote plant growth. Bio-inoculants are microbial preparations of a single or consortia of living microorganisms. The methylotrophic bacteria are important bio-inoculants. Methylotrophs comprise a sub population of the bacteria that are able to metabolize single carbon compounds (methanol, methylamine, or other C1 carbon compounds) as sole sources of carbon and energy. They are an important group of bacteria that taken up greenhouse gases and therefore minimize global warming, in addition to actively participating in carbon cycling in the soil (Kolb and Stacheter 2013; Jeyajothi *et al.,* 2014). The many functional attributes of methylotrophs in sustainable agriculture are classified into three subgroups on the basis of their carbon substrate utilization: (1) methylotrophs utilizing single carbon compounds are designated obligates, (2) methylotrophs utilizing a limit range of complex carbon compounds other than C1 compounds are considered restricted facultative and (3) methylotrophs able to grow on a wide range of complex carbon compounds are less-restricted facultative (Iguchi *et al.,* 2015). Biocapture of C1-VOCs from the plant phyllosphere has also been reported (Bringel and Couee, 2015). Moreover, methylotrophs regulate carbon cycling and therefore may reduce global warming. In the carbon cycling, methylotrophs plays a key between greenhouse gases like CO2 and methane (Iguchi *et al.,* 2015). This review provides an overview in the involvement of the methylotrophic microbiome in carbon, nitrogen, and phosphorous cycling and its role in making agriculture sustainable.Abd El-Gawad *et al.* (2015) concluded that application of 100 per cent recommended dose of NPK along with foliar application of pink pigmented facultative methylotrophic bacteria @ 5 per cent twice recorded the highest growth and pod yield of snap bean as compared to control. Manish Kumar *et al.* (2016) indicated that combined application of recommended dose of fertilizer (150:50:50 kg NPK ha-1) along with FYM @ 12.5 t ha-1 + biofertilizer namely azophosmet as soil and seed treatment and foliar spray of pink pigmented facultative methylotrophs (PPFM) @ 1.0% at twice significantly registered the highest microbial population like bacteria, fungi and actinomycetes as compared to control. Methylobacterium species are a group of bacteria known as pink-pigmented facultative methylotrophs or PPFMs and exogenous application of PPFM produces some benefit in alleviating the adverse effects of drought stress as well as salinity and also improves germination, growth development, quality and yield of crop plants (Sivakumar *et al.,* 2017).

6. Role of micronutrients in crop production

They improve general condition of plants and are known to act as catalysts in promoting organic reactions taking place in plant. Direct application of micronutrients like zinc, manganese, copper, iron, molybdenum, boron and chelated forms of micronutrients are recommended for better yields. The chelating agents of the metal ions protect the chelated ions from unfavorable chemical reactions and hence increase the availability of these ions to plants. Large numbers of metal complexing agents are available to chelate micronutrients. Further, the uptake of these micro nutrition through the roots or foliage and their transformation in plants and possibility of their influence on metabolism is comparatively superior as it is supplied in chelated form. Now a day’s foliar nutrition is becoming an established nutrient supplementation technique in crop production to increase the yield and quality of oilseed crops (Singh*,* 2004). Micronutrients are usually required in a small quantity, nevertheless play a vital role to the crop growth of plant. Especially zinc (Zn) and manganese (Mn) are important micronutrients in sesame production. Reduced growth hormone production in Zn deficient plants causes shortening of internodes and short leaves which resulted in malformation of capsule with less number seed filling or low seed yield of sesame (Havlin *et al.,* 2005). Indian soils are extensively deficient in micronutrient and 5.4 per cent soil of India recorded Cu deficiency. Incidence of micronutrient deficiencies in crop has increased markedly in recent years due to intensive cropping, loss of top soil by erosion, loss of micronutrient through leaching, liming of acid soils, decreased proportions of farmyard manure compared with chemical fertilizer, increased purity of chemical fertilizer and use of marginal lands for crop production micronutrient deficiency problem also aggregates by high demand of modern crop cultivar (Bell and Dell, 2006). Small amount of nutrient, particularly Zn, Fe and Mn applied by foliar spraying increase significantly the yield of crop (Sarkar *et al.,* 2007). Application of zinc, boron and manganese significantly increase number of capsule, seed yield, number of seed per capsule and 1000 seed weight. The incidence of micronutrient deficiencies in crop has increased due to intensive cropping, loss of top soil by erosion, losses of micronutrient through leaching and use of marginal land for crop production (Cakmake, 2008). Micronutrient has a vital role for proper growth and function of plants. Even crop plants require micronutrient in very minute quantities but their deficiency may affect vital physiological and biochemical process and causing hormonal imbalance, hence reduction in yield of oil crops (Sadeghzadeh, 2013). Micronutrient plays a vital role in crop growth, crop productivity, soil fertility and human nutrition. Foliar fertilization is a simple, efficient, economic and also improves the use efficiency of applied nutrients (Chattopadhyay *et al.,* 2003; Fageria *et al.,* 2009; Shirazy, *et al*., 2015;Elayaraja, 2016). Micronutrient or trace elements are essential for plant growth and development but it is needed in very small quantities in plant system. It includes Fe, Cu, Cl, Mn, B, Ni, Zn and Mo (Rahman *et al.,* 2020).

6.1. Role of zinc in crop plants

Zinc is important micronutrient in sesame production. Reduced growth hormone production in Zn deficient plant cause shortening of internodes and short leaves resulting in malformation of fruit with little or no yield (Prakash and Ganesan, 2000). Zinc play a key role in structural or regulatory cofactor of different enzyme and protein in many biochemical pathway like carbohydrate, metabolism, photosynthesis, conversion of sugar to starch protein metabolism, auxin metabolism. Pollen formation membrane and resistance to infiltration by certain pathogen. Micronutrient is involved in the key physiological process of photosynthesis and respiration (Marschner, 2002). Zinc is an essential micronutrient and plays a key role as a structural constituent or regulatory cofactor of a wide range of different enzymes and proteins in many important biochemical pathways like carbohydrate metabolism, photosynthesis, conversion of sugars to starch, protein metabolism, auxin (growth regulator) metabolism, pollen formation, integrity of biological membranes and resistance to infection by certain pathogens (Alloway, 2008). Zinc plays an important role in several enzymes systems. Zinc catalyze the process of exudation in plant cell and is vital for the transformation of carbohydrates, influences the formation of chlorophyll, helps in the formation of auxins, the growth promoting compounds. It promotes the absorption of water and in doing so prevents the stunting of plants. It acts as a component of enzymes proteinase, dehydrogenase and peptidase. A number of these dehydrogenase show sensitivity to zinc deficiency (Abbasi *et al.,* 2010). However, micronutrient deficiency can result in great deal of limitation in the physiological and metabolic process ever in plants need only small amount of micronutrient for satisfactory crop growth and production (Datir *et al*., 2012)Zinc plays a vital role in regulating plant metabolic functions, such as formation of hormones (IAA), tryptophan and auxins. It is a component of several enzymes and plays an important role in nucleic acid, ribosomes and protein synthesis in cells. In addition it helps in seed formation, promotes water absorption and translocation of carbohydrates in plants (Asha *et al.,* 2012 and Meena *et al.,* 2012). Zinc is needed in small, but critical concentrations and if the amount available is not adequate, plants will suffer from physiological stress. Under Zn-deficient conditions, flowering and capsule development is reduced, and growth period is prolonged resulting in delayed maturity, leading to lower yield, poor quality and suboptimal nutrient use efficiency (Suresh *et al.,* 2013).

6.2. Role of manganese in crop plants

Manganese play a vital role in photosynthesis reaction, nitrogen metabolism and to form other compounds required for plant metabolism enzyme activation and root growth (Mortvedt *et al.,* 1999). Manganese is one of the most important micronutrients especially sesame, which has an important role in plants as a component of enzymes involved in photosynthesis and other processes. Manganese is part of an important antioxidant (superoxide dismutase) structure that protects plant cells by deactivating free radicals which can destroy plant tissue (Millaleo *et al.,* 2010 and Mousavi *et al.,* 2011). Manganese is uptake by plant roots as the divalent ion Mn2+. In addition, Mn activates several important metabolic reactions, aids in chlorophyll synthesis, in photosynthesis, accelerates germination and maturity and increases the availability of P and Ca. Manganese is not translocated in the plant, so symptoms first appear on younger leaves, as with Zn and Fe; however, there appears to be some translocation of Mn in crops. Inadequate Mn results in chlorosis of new leaves and slower growth. Severe Mn deficiency in crop plants can cause significant loss in yield (Shehu, 2014).

**7. Effect of micronutrients and organics on the growth and yield of sesame**

Jain *et al.* (2000) revealed that the application of recommended dose of NPK (40:30:20 N, P2O5, K2O kg ha-1) along with FYM @ 10 t ha-1 and MgSO4 @ 30 kg ha-1 + ZnSO4 @ 15 kg ha-1 recorded the highest seed yield of sesame as compared to control. Singaravel *et al.* (2001) indicated that application of recommended dose of NPK (35:22.5:22.5 kg ha-1) + soil application of ZnSO4 25 kg ha-1 + MnSO4 @ 5 kg ha-1 recorded the highest character like plant height (105 cm) and dry matter production (2805 kg ha-1) yield character *viz.,* number of capsule plant-1 (59.1), number of seed capsule-1 (57.0), 1000 seed weight (3.04 g), seed yield (794 kg ha-1) and stalk yield (2299 kg ha-1) of sesame as compared to control. Thiruppathi *et al*. (2001) reported that application of 35:23:23 N, P2O5, K2O ha-1 + ZnSO4 @ 5 kg ha-1 (soil application) + ZnSO4 @ 0.5% twice at 40 and 55 DAS   
(foliar spray with azopirillium (seed treatment) recorded significantly higher number of capsule plant-1 (99.84), number of seed capsule-1 (53.61), 1000 seed weight (3.35 g), seed yield (1162.66 kg ha-1), stalk yield (3349.89 kg ha-1) and harvest index (25.76) of sesame.Narkhede *et al*. (2001) revealed that combined application of NPK   
@ 40:30:20 kg ha-1 + FYM @ 10 t ha-1 along with ZnSO4 @ 10 kg ha-1 recorded the highest seed yield (450 kg ha-1) of sesame as compared to control (without zinc). Simon (2001) suggested that the integrated application of NPK + foliar application of MnSO4 @ 0.5 per cent along with FYM @ 12.5 t ha-1 and *Azospirillum* recorded the highest growth, yield attributing characters and yield of sesame. Jayasingh (2002) found that foliar application of MnSO4 @ 0.5 per cent twice at 30 and 45 DAS along with *Azospirillum* seed treatment and recommended dose of NPK for sesame crops grown on manganese deficient soils recorded the higher seed yield than control. Imayavaramban *et al*. (2002) reported that combined application of recommended dose of NPK fertilizer + FYM @ 12.5 t ha-1 along with micronutrients (ZnSO4 + MnSO4) through soil as well as foliar spray recorded the highest growth, yield attributes and yield of sesame over recommended dose of NPK alone.

Chaube *et al.* (2002) reported that soil application of ZnSO4 @ 25 kg ha-1 has recorded significantly higher pod yield (3888 kg ha-1) haulm yield (5218 kg ha-1) and seed yield (2512 kg ha-1) of groundnut as compared to control (3366 kg ha-1, 4653 kg ha-1 and 2155 kg ha-1 respectively. Paramasivam *et al.* (2003) noticed that application of micronutrients like MnSO4 + borax and ammonium molybdate recorded the maximum plant height (96.6 cm), dry matter production (19.9 g plant-1) and number of capsule plant-1 (37.0) as compared to control. Prakash *et al.* (2003) reported that foliar application of MnSO4@ 0.3 per cent recorded the higher number of capsules plant-1 (64.8), number of seeds capsule-1 (33.43), 1000 seed weight (2.82 g) and seed yield (459.42 kg ha-1) of sesame as compared to control.Duhoon *et al*. (2004) indicated that application of FYM @ 2.5 t ha-1 + phosphorus solublizing bacteria (PSB) + Azotobacter + Gypsum @ 250 kg ha-1 along with rock phosphate enriched with FYM @ 20 kg ha-1 recorded the highest seed yield (697 kg ha-1) of sesame as compared to control. Purushottam (2005) found that application of micronutrients (Zn, Fe, Mn and Cu) + FYM along with recommended dose of NPK fertilizer registered the highest growth attributes, yield attributes and seed yield of sesame.Mondal and Ghosh (2005) revealed that combined application of 75 per cent recommended dose of NPK (40:20:20 kg N:P2O5:K2O ha-1) along with FYM @ 10 t ha-1 recorded the highest seed yield (695 kg ha-1) of sesame as compared to control. Singaravel *et al*. (2006) observed that the combine application of Zn + B along with composted coir with and humic acid significantly increased the growth *viz.,* plant height (63.10 cm), dry matter production (53.13 g pot-1) and pod and haulm yield (33.40 and 48.07 g pot-1) respectively.

Krishnaprabu and Kalyanasundaram (2007) suggested that foliar application of macro (Haileaf @ 3.0 g lit-1) along with micro (Microsol @ 0.5 g lit-1) nutrients on 30 and 45 DAS along with recommended dose of NPK recorded the highest growth characters like plant height (103.48 cm) and dry matter production (3608 kg ha-1) and yield characters like number of capsules plant-1 (85.71), number of seeds capsule-1 (62.37) and seed yield (902 kg ha-1) of sesame, respectively over control (NPK alone). Ravi *et al.* (2008) reported that foliar application of Fe @ 0.5% + Zn @ 0.5% at 30 and 45 DAS recorded significantly higher growth parameter like plant height (97.5 cm), number of leaves (81.5), primary plant-1 (10.8), secondary plant-1 (17.3) and dry matter production (2440.7 kg ha-1) of safflower as compared to control. Chaurasia *et al.* (2009) observed that application of 100 per cent recommended dose of fertilizer (60:40:20 NPK kg ha-1) + FYM @ 12.5 t ha-1 + ZnSO4 @ 20 kg ha-1 along with FeSO4 @ 25 kg ha-1 significantly increased the growth characters *viz*., plant height and number of branches plant-1 and yield characters *viz*., number of capsules plant-1, number of seeds capsule-1, 1000 seed weight and seed yield of sesame.Yadav *et al.* (2009) indicated that application of 100 per cent recommended dose of NPKS fertilizer (40:20:20:30 kg NPKS ha-1) + FYM @ 2.5 t ha-1 along with micronutrients namely ZnSO4 @ 20 kg ha-1 + FeSO4 @ 25 kg ha-1 registered the highest growth attributes like branches plant-1 (4.45) and dry matter production (3560 kg ha-1); yield attributes like number of capsules plant-1 (53.35), seed weight plant-1 (5.65 g), and 1000 seed weight (3.75 g) of sesame. They also reported that the combined application of 100 % RDF + ZnSO4 @ 20 kg ha-1 + FeSO4 @ 25 kg ha-1 along with FYM @ 2.5 t ha-1 recorded the highest seed yield (899 kg ha-1) of sesame.

Prasanna Kumar (2009) revealed that the integrated application of 150% recommended dose of NPK (40:25:25 kg ha-1 N, P2O5 and K2O) + vermicompost along with micronutrients (MnSO4, ZnSO4, FeSO4 each @ 5 kg ha-1 and borax   
@ 10 kg ha-1 along with planofix and Ethephan @ 50 ppm registered the highest growth, yield characters and seed yield of sesame as compared to control.   
Shaikh *et al*. (2010) revealed that application of 100 per cent recommended dose of fertilizer + FYM @ 5.0 t ha-1 + vermicompost @ 5.0 t ha-1 along with seed treatment of Azospirillum and Phosphorus Solublizing Bacteria increased the seed weight   
(7.07 g plant-1), seed yield (15.19 q ha-1) and straw yield (33.86 q ha-1) of sesame, respectively over no fertilizer application. Javia *et al*. (2010) reported that in sesame, application of 100% recommended dose of fertilizer @ 50:25:25 kg NPK kg ha-1 along with 5.0 t FYM ha-1 and ZnSO4 @ 25 kg ha-1 registered highest grain yield of 508 kg ha-1 over control (NPK alone). Akbari *et al*. (2011) concluded that application of 100 per cent NPK along with enriched compost @ 6.0 t ha-1 recorded the highest seed yield of 360 kg ha-1. Malligawad (2010) indicated that integrated application of organic manures + inorganic fertilizers to sesame produced higher seed yield of 566 kg ha-1 as compared to control. Umar *et al*. (2010) reported that application of recommended dose of inorganic fertilizer along with organic manures ensured higher yield of sesame than compared to individual application of inorganic fertilizer alone or organic manures alone. Salwa *et al*. (2010) reported that in a sandy soil, increased growth and highest seed yield of sesame was obtained with sulphur, amino acids and micronutrients (Fe, Zn and Mn @ 900, 450 and 450 g g-1). The increased rate of NPK fertilizer application significantly increased the higher dry matter production and seed yield of sesame than compared to control (Shehu *et al.*, 2010).

Ravi and Channal (2010) observed that application of NPK (75:75:45 kg N, P2O5 and K2O ha-1) + 30 kg S ha-1 along with Fe + Zn foliar spray recorded   
the highest growth characters like plant height (114 cm) and dry matter production (3184 kg ha-1) and yield characters like number of capsules plant-1 (37.1), seed weight head-1 (0.96 g), 1000 seed weight (68.2 g) and seed yield (1765 kg ha-1) of safflower as compared to control. Malligawad (2010) studied that the effect of different nutrient management practices on the productivity of sesame and sorghum cropping system. They reported that the integrated nutrient management practices involving the application of organic manure and inorganic fertilizers (Recommended dose of fertilizer like 40 kg N, 25 kg P2O5, 25 kg K2O and 5 kg ZnSO4 ha-1 + FYM @ 5 t ha-1 along with phosphorus solubilizing bacteria and *Azospirillum* (seed treatment) significantly higher seed yield of sesame (566 kg ha-1) and sorghum (2531 kg ha-1) cropping system as compared to control (inorganic fertilizers alone).Javia *et al.* (2010) reported that the application of 100% recommended dose of fertilizer @ 50:25:25 kg NPK ha-1 along with 5.0 t FYM and ZnSO4 registered the highest seed yield (508 kg ha-1) of sesame as compared to control. Deshumkh *et al.* (2010) stated that integrated application of recommended dose of fertilizers (60:40:20 kg NPK ha-1) + FYM @ 5 t ha-1 + vermicompost @ 5 t ha-1 and seed treatment with Azospirillum and PSB recorded the highest growth characters *viz.*, plant height and number of branches plant-1 and yield attributes *viz*., number of capsules plant-1 and 1000 seed weight of sesame. Kobrace *et al.* (2011) reported that soil application of Mn @ 40 kg ha-1 recorded significantly higher number of seed plant-1 (62.67), 1000 seed weight (1781g), seed yield (3493 kg ha-1) of soyabean as compared to control (49.67 plant-1, 17.12g and 2627 kg ha-1).

Elayaraja and Singaravel (2012) reported that in a coastal sandy soil, the highest pod (2466 kg ha-1) and haulm (3354 kg ha-1) yield of groundnut was obtained with 150 per cent NPK + ZnSO4 @ 30 kg ha-1 + Borax @ 15 kg ha-1 along with composted coir pith @ 12.5 t ha-1. Karthikraja (2012) revealed that foliar application of ZnSO4 and MnSO4 @ 0.5 per cent twice at 30 and 45 DAS significantly increased the growth and yield of sesame. Bhadauria *et al.* (2012) stated that soil application of Zn @ 10 kg ha-1 recorded significantly higher seed yield (18.90), stover yield (56.95 g ha-1) and oil content (39.43%) in mustard has compared to control.Elayaraja (2013) concluded that in coastal sandy soil, the combined application of 150 per cent recommended dose of NPK (35:23:23 kg NPK ha-1) + ZnSO4 @ 25 kg ha-1 + MnSO4 @ 5 kg ha-1 along with FYM @ 12.5 t ha-1 recorded the highest seed (52.39 g pot-1) and stalk yield (184.69 g pot-1) of sesame as compared to control. Islam *et al.* (2013) indicated that application of IPNS basis inorganic fertilizer dose of N, P, K, S, Zn and B 149:37:22:7:7 kg ha-1 along with cow dung slurry 5 t ha-1 recorded the highest plant height (136.80 cm), number of seeds capsule-1 (44.47), 1000 seed weight (2.68 g), seed yield (1.31 t ha-1) and stover yield (3.53 t ha-1) of sesame as compared to control. Ghosh *et al.* (2013) observed that the uptake of nutrient by sesame was under 751. RDF + 26% N through FYM + Azospirillum in sesame increased the growth *viz.,* plant height (97.2 cm), number of branches plant -1(4.6), plant dry weight (703 g m-2), number of capsule (32.8), number of seed capsule-1 (54.5) and seed yield (1406 kg ha-1).Bharathi *et al.* (2014) revealed that application of recommended dose of   
NPK + seed treatment with Azospirillum + soil application of MnSO4 @ 5 kg ha-1 + clipping at 0 + 2 leaf stage along with planofix spraying @ 30 ppm at 45 and at   
55 DAS recorded highest number of capsules per plant (91.12), number of seeds per capsule (69.82), seed yield (1160.75 kg ha-1) and stover yield (3133.61 kg ha-1) of sesame as compared to control (RDF alone). Sidhu *et al.* (2015) studied that application of recommended dose of chemical fertilizer along with sulphur application @ 40 kg ha-1 through ZnSO4 recorded significantly higher plant height, number of capsules, seeds capsules-1, 1000 seed weight, seed yield and stalk yield of sesame.

Elayaraja (2016) stated that 150% NPK along with ZnSO4 @ 25 kg ha-1 + MnSO4 @ 5 kg ha-1 has recorded the highest seed and stalk yield (52.4 and 184.7 g plot-1) and growth parameter like *viz.,* plant height (94.1 cm), number of branches plant–1 (7.35), dry matter production (189.4 g pot-1), yield number of capsule plant-1 (39.06), number of seed capsule-1 (38.3) and 1000 seed weight (2.84 g). Habimana *et al.* (2016) stated that application of Mn through MnSO4 @ 10 kg ha-1 increased the seed yield (740 kg ha-1) and oil yield (368.10 g ha -1) of sesame.Ahiwar *et al.* (2017) observed that the application of 100% RDF +   
50% RDN through FYM recorded the highest number of capsule plant-1 (31.40), number of seed capsule-1 (28.66) and test weight (3.20 g) of sesame, respectively. Takar *et al.* (2017) reported that applications of FYM @ 5 t ha-1 + castor cake @ 250 kg ha-1 + vermicompost @ 750 kg ha-1 produced the highest seed yield   
(82.4 kg ha-1), stalk yield (104 kg ha-1) and oil content (51.84%) of sesame. Raghavendra *et al.* (2020) revealed that growth and yield components of sunflower were influenced favorably by soil application of ZnSO4 @ 10 kg ha-1 + foliar application of FeSO4 @ 0.5% along with RDF and FYM @ 10 t ha-1 recorded significantly highest growth parameter *viz.,* plant height, dry matter production, seed and stalk yield of sunflower. Several investigators through various field experiments concluded that application of micronutrients through soil or foliar and both soil as well as foliar or in combination along with recommended dose of NPK and organics registered the highest growth and yield of sesame (Beema, 2016, Takar *et al.,* 2017 and Seervi *et al.,* 2018).

8. Effect of micronutrients and organics on the quality parameters of sesame

Thiruppathi *et al*. (2001) observed that, integrated application of 100 per cent NPK (35: 23: 23 kg N, P2O5 and K2O ha-1) + ZnSO4 @ 5 kg ha-1 (soil application) + ZnSO4 @ 0.5 per cent twice at 40 and 55 DAS (foliar spray) + planofix @ 30 ppm twice at 40 and 55 DAS (foliar spray) along with Azospirillum (seed treatment) recorded the highest protein and oil content of sesame seeds as compared to control. Duhoon *et al*. (2004) indicated that application of FYM @ 2.5 t ha-1 + phosphorus solublizing bacteria (PSB) + Azotobacter + Gypsum @ 250 kg ha-1 along with rock phosphate enriched with FYM @ 20 kg ha-1 recorded the highest seed yield (697 kg ha-1) and oil yield (354 kg ha-1) of sesame. Salwa *et al*. (2010) revealed that quality parameters of sesame seeds,   
such as oil content (56.0%), protein content (17.24%), oil yield (624 kg ha-1) and protein yield (192.5 kg ha-1) could be improved by applying micronutrients along with sulphur and amino acid. Tripathy and Bastia (2012) indicated that, the application of 50 per cent recommended dose of NPK fertilizer (30:6.6:12.5 kg ha-1 of NPK) along with FYM @ 5 t ha-1 recorded the highest oil yield (437 kg ha-1) of sesame seeds as compared to NPK alone (without organics). Sidhu *et al*. (2015) observed that application of recommended dose of fertilizer along with sulphur application @ 40 kg ha-1 through ZnSO4 recorded the higher crude protein and oil content of sesame seeds as compared to control. Habimana *et al*. (2016) stated that application of recommended NPK (35:23:23:40 kg ha -1 +30 kg MnSO4 recorded the higher oil content (49.17%) protein content (15.52%) oil yield (369 kg ha-1) protein yield (114.86 kg ha-1) of sesame. Ahiwar *et al.* (2017) observed that the application of 100% RDF +   
50 RDN through FYM recorded the higher oil content and oil yield of sesame (43.34%, 190 kg ha-1). Choudhary *et al.* (2017) reported that application of organic manure FYM @ 5 t ha-1 + vermicompost @ 2.5 t ha-1 and mineral nutrient S @ 20 kg ha-1 + Fe @ 10 kg ha-1 + Zn @ 5 kg ha-1 significantly increased protein content (24.51%) oil content (49.71%) oil yield (482.97 kg ha-1) of sesame.

Takar *et al.* (2017) noted that application of FYM @ 5 t ha-1 + castor cake @ 250 kg ha-1 + vermicompost @ 750 kg ha-1 has highest major nutrient content in seed N (4.35%), P (0.57%), K (0.55%) and in stalk (0.86%, 1.85%, 0.55%) NPK, respectively. Seervi *et al.* (2018) conducted a field experiment during kharif season 2017 to study the effect of micronutrient applied as foliar spray on yield, yield attributes and oil content of sesame crop. The results of the study indicated that foliar spray of zinc @ 100 ppm as (ZnSO4) increased the oil content 49.3% of sesame when compared to other micronutrients. Raghavendra *et al.* (2020) revealed that application of ZnSO4 @ 10 kg ha-1 + foliar spray of FeSO4 @ 0.5% along with RDF and FYM @ 8 t ha-1 recorded significantly the highest oil content (41.3%) in sesame.

9. Effect of micronutrients and organics on the nutrients uptake by sesame

Thiruppathi *et al*. (2001) noted that integrated application of 100 per cent RDF @ 35:23:23 kg N, P2O5 and K2O ha-1 + ZnSO4 @ 5 kg ha-1 (Soil application) +   
ZnSO4 @ 0.5% Twice at 40 and 55 DAS (foliar Spray) + Plaufix @ 30 ppm twice at 40 DAS (foliar spray) along with Azospirillum (seed treatment) recorded the highest N (73.41 kg ha-1), P (19.58 kg ha-1) and K (42.16 kg ha -1) uptake by sesame.Singaravel *et al.* (2001) revealed that in sesame, application of 100 per cent NPK + ZnSO4 @ 25 kg ha-1 + MnSO4 @ 5 kg ha-1 through soil application recorded the highest nitrogen (25.77 and 46.11 kg ha-1), phosphorus (51.18 and 5.88 kg ha-1), potassium (53.01 and 47.46 kg ha-1), zinc (0.036 and 0.121 kg ha-1), manganese (0.064 and 0.92 kg ha-1) and iron (0.060 and 0.92 kg ha-1) uptake by seed and stalk, respectively. Hanumanthappa and Shivaraj (2003) reported that addition of 100 per cent NPK along with composted coirpith @ 3.8 t ha-1 recorded the highest N, P and K uptake by sesame as compared to control. Mondal and Ghosh (2005) revealed that the integrated application of 75 per cent recommended dose of NPK (40:20:20 kg N:P2O5:K2O ha-1) along with FYM @ 10 t ha-1 recorded the highest N (94.6kg ha-1), P (24.1 kg ha-1) and K (59.4 kg ha-1) uptake by sesame as compared to control. Singaravel *et al*. (2006) revealed that in groundnut highest nitrogen uptake by pod (1437.4 mg plant-1) and haulm (1098.8 mg plant-1), phosphorus uptake by pod (172.32 mg plant-1) and haulm (189.38 mg plant-1), potassium uptake by pod 379.91 (mg plant-1) and haulm (879.89 mg plant-1) were obtained by the combined application of composted coir pith and humic acid along with micronutrients (Zn + B) in coastal saline soil.

Krishnaprabu and Kalyanasundaram (2007) concluded that foliar application of macro (Haileaf @ 3.0 g lit-1) along with micro (Microsol @ 0.5 g lit-1) nutrients and recommended dose of NPK recorded the highest N, P and K uptake by sesame as compared to control (NPK alone). Elayaraja (2008) reported that in coastal sandy soil, application of 150 per cent recommended dose of NPK (17:34:54 kg N, P2O5 and   
K2O ha-1) + ZnSO4 @ 30 kg ha-1 + borax @ 15 kg ha-1 along with composted coirpith @ 12.5 t ha-1 recorded the highest major nutrients (N, P and K) and micronutrients (Zn, Cu, Fe, Mn and B) uptake of groundnut by pod and haulm as compared to control (without micronutrient and organics).

Ravi and Channal (2010) noted that the application of RDF (NPK @ 75:75:45 N: P2O5: K2O kg ha-1) + S @ 30 kg ha-1 along with Fe + Zn Foliar Spray recorded   
the highest nutrient uptake such as N (84.38 kg ha-1), P (9.49 kg ha-¹), K (66.35 kg ha-¹), S (12.41 kg ha-1), Zn (408.89 g ha-1) and Fe (1.95 g ha-1) by safflower. Salwa *et al*. (2010) reported that in a sandy soil, combined application of micronutrients (Fe, Zn and Mn) along with sulphur and amino acid was recorded the highest P (0.54%), K (2.44%), Fe (319 μg g–1), Zn (77 μg g–1) and Mn (32.0 μg g–1) content of sesame seeds, respectively. The increased rate of NPK fertilizer application significantly increased the NPK content and uptake by sesame (Shehu *et al.*, 2010). Grzebisz *et al.* (2010) revealed that application of recommended dose of NPK along with multi micronutrient applied through foliar spray (multi micronutrient fertilizer contains: Cu-70; Fe-400; Mn-170; Zn-150 and Mo-40 mg L-1 chelated by EDTA) significantly improved the nitrogen, phosphorus, potassium, calcium and magnesium content by rapeseed as compared to control (without multi micronutrient).Elayaraja and Singaravel (2012) reported that in a coastal sandy soil, the highest yield and nutrient uptake by groundnut was obtained with 150 per cent   
NPK + ZnSO4 @ 30 kg ha-1 + Borax @ 15 kg ha-1 along with composted coir pith   
@ 12.5 t ha-1. Tripathy and Bastia (2012) noted that the integrated application of   
50 per cent NPK fertilizer (30: 6.6: 12.5 kg ha-1 of NPK) along with FYM @ 5 t ha-1 was recorded the highest nitrogen (29.6 kg ha-1), phosphorus (11.2 kg ha-1) and potassium (29.9 kg ha-1) uptake by summer sesame. Elayaraja (2013) revealed that the integrated application of Zn and Mn (ZnSO4 @ 25 kg ha-1 + MnSO4 @ 5 kg ha-1) along with 150 per cent recommended dose of NPK and FYM @ 12.5 t ha-1 recorded the highest macro (N, P and K) and micronutrients (Zn and Mn) uptake by seed and stalk of sesame than compared to control.

Ghosh *et al.* (2013) observed that the uptake of nutrient by sesame was higher under the treatment 75% RDF + 26% N through FYM + Azospirillum by recorded nitrogen (54.0 kg ha-1), phosphorus (21.6 kg ha-1) and potassium (54.5 kg ha-1). Elayaraja (2016) stated that 150% NPK along with ZnSO4 @ 25 kg ha-1 + MnSO4 @ 5 kg ha-1 has recorded the significant pH (8.41), EC (1.65 dSm-1), organic carbon 2.3 (g kg-1) and micronutrients uptake by sesame like zinc (0.70 mg kg-1), Mn (0.96 mg kg-1). However, the beneficial effect of 150% NPK along with ZnSO4 @ 25 kg ha-1 + MnSO4 @ 5 kg ha-1 enhances the nutrient availability in soil such as alkaline KMnO4-N (1341 kg ha-1), Olsen P (9.3 kg ha-1) and NH4OAC-K (1535 kg ha-1).

Elayaraja and Dhanasekaran (2016) concluded that in coastal sandy soil, application of recommended dose of NPK + composted coirpith @12.5 t ha-1 along with soil application of Zn-humate @ 30 kg ha-1 + foliar spray of Zn-humate @ 0.5 per cent recorded the highest nitrogen (56.58 and 32..85 kg ha-1), phosphorus (16.08 and 10.89 kg ha-1), potassium (46.18 and 31.75 kg ha-1) and zinc (123.00 and 96.62 g ha-1), uptake by bhendi fruit and stover, respectively. Takar *et al.* (2017) stated that FYM   
@ 5 ton ha-1 + castor cake @ 250 kg ha-1 + vermicompost @ 750 kg ha-1 has recorded the highest nutrient uptake of NPK (36.01 kg ha-1, 4.80 kg ha-1, 7.87 kg ha-1) by seed and (30.38 kg ha-1, 4.71 kg ha-1, 15.72 kg ha-1) in stalk, respectively on sesame.Arulrajasekaran *et al*. (2019) concluded that application of 100% recommended dose of NPK + 75% Zn and Fe along with bioactive compounds fortified organic manure @ 5 t ha-1 improved the yield, nitrogen, phosphorus, potassium, Zn and Fe uptake by blackgram under coastal sandy soil as compared to control. Parmar *et al.* (2020) revealed that application of 50% RDF + 5.0 ton FYM ha-1 + PSB + Azotobacter significantly improved the NPK and S uptake by seed (29.75, 7.52, 6.74, 4.78 kg ha-1) and stalk (27.68, 12.45, 22.18, 9.84 kg ha-1), respectively.

10. Effect of micronutrients and organics on the soil fertility

Solaimalai *et al.* (2001) and Balaguravaiah *et al.* (2005) reported that application of coirpith can be used as soil amendment under varied soil condition, for improving the physical, chemical and biological properties of soil. It is good source of mulch for increasing the water holding capacity to sandy loam and sandy soil. Varalakshmi *et al.* (2005) observed that the application of 100 per cent recommended NPK + FYM @ 7.5 t ha-1 resulted in higher soil organic carbon, available N, P2O5 and K2O in the post-harvest soil. Mann *et al.* (2006) indicated that application of farmyard manure @ 10 t ha-1 along with 100 per cent NPK fertilizers increased the organic carbon (0.8%) and availability of NPK in *Typic Ustochrept.* Chalwade *et al.* (2006) indicated that application of 50% recommended dose of NPK along with FYM @ 4 t ha-1 increased the organic carbon, available N, P and K in soil as compared to recommended dose of fertilizer and control.Chang *et al.* (2007) indicated that application of compost @ 540 kg N ha-1 along with recommended dose of chemical fertilizer significantly increased the organic matter content, total nitrogen, phosphorus and potassium with significant reduction of pH and EC in soil. This treatment also recorded the highest microbial population like bacteria, fungi and actinomycetes and enzymatic activities soil. Agasimani *et al.* (2007) concluded that combined application of poultry manure along with 100 per cent recommended dose of fertilizer recorded higher organic carbon and available N, P and K in the post-harvest soil. Elayaraja (2008) reported that in a coastal sandy soil, there is a improved organic carbon, nutrient availability (N, P, K, Zn, B, Fe and Cu), enzymatic activity (urease, phosphatase and dehydrogenase) and significant reduction on pH, EC of the soil was obtained by application of 150 per cent recommended dose of NPK + ZnSO4 @ 30 kg ha-1 + borax @ 15 kg ha-1 along with composted coir pith @ 12.5 t ha-1

Akande *et al.* (2010) reported that application of recommended dose of NPK along with organic based fertilizer (OBF) @ 2.5 M t ha-1 recorded the highest available macro (N, P, K) and micro (Zn, Fe, Mn, Cu) nutrients status in the post-harvest soil. Javia *et al*. (2010) indicated that in sesame, application of 100 per cent recommended dose of NPK (50:25:25 kg NPK ha-1) along with FYM @ 5.0 t ha-1   
and ZnSO4 @ 8 kg ha-1 resulted in higher organic carbon, available major nutrients (N, P and K) and micronutrients (DTPA-Zn, Mn, Fe and Cu) in the post-harvest soil as compared to control. Akbari *et al*. (2011) concluded that application of 100 per cent NPK along with zinc enriched compost @ 6.0 t ha-1 significantly increased the higher organic carbon, available major and micronutrients content of the soil. Adeniyan *et al.* (2011) indicated that significant increase in organic carbon, total nitrogen, available phosphorus and exchangeable potassium status of soil with application of 100 per cent NPK along with FYM @ 12.5 t ha-1 as compared to control (NPK alone). Patnaik *et al.* (2012) reported that application of graded levels of Zn as zinc sulphate (0, 25, 50 and 100 kg ZnSO4 ha-1) significantly increased available DTPA-extractable Zn fraction of soil.Pareek *et al.* (2012) reported that application of graded levels of zinc sulphate (0, 5, 10, 15, 20, 25, 30 and 35 kg Zn ha-1) along with recommended dose of NPK (120:40:30 kg NPK ha-1) significantly improved the available zinc content in post-harvest soil. The highest available zinc content (0.711 mg kg-1) of soil was significant up to 30 kg of Zn ha-1.

According to Venkatakrishnan and Dhanasekaran (2012) the available nitrogen, phosphorus, potassium and zinc content of the post harvest soil increased due to the combined application of ZnSO4 @ 25 kg ha-1 through soil + foliar spray of 0.5 per cent Zn along with recommended dose of NPK (75:100:50 kg NPK ha-1) as compared to control. Kumawat *et al.* (2012) concluded that the combined application of 100 per cent recommended dose of fertilizers (20:40:20:20 kg N, P2O5, K2O and S ha-1) + 50 per cent recommended dose of nitrogen through vermicompost along with 5 kg Zn ha-1 registered higher available NPK status of the post harvest soil as compared to control (NPK alone). An overall improvement in the physical (decreased bulk density, particle density and increased water holding capacity), chemical (decreased pH, EC and increased organic carbon, available N, P, K and micronutrients) and biological (bacteria, fungi, actinomycetes and urease, phosphatase and dehydrogenease activity) properties of soil was noticed with recommended dose of NPK + biofertilizer and composted coirpith along with micronutrients like zinc and boron application under coastal saline soil condition (Elayaraja, 2008; Beema, 2016; Sivaranjini, 2017; Ramamoorthy, 2018, Karthika, 2019 and Vigneshwarraj, 2020).

From the literature investigated form various sources clearly showed that the beneficial effect of fortified organics and micronutrients fertilization could be viable option for augmenting sesame production in coastal saline soil. Organic manures, micronutrient fortified organic manures, NPK fertilizers alone or in combined application of these nutrient sources have significant role in mitigating saline stress along with crop productivity and soil fertility. However, in specific soil test based or site specific nutrient management studies required for various oil seed crops that can be grown under salt stress .In addition to that combined management plant and soil breeding research work has to explored for better management salinity and their productivity.

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