CHAPTER- II

Review of Literature
REVIEW OF LITERATURE

Keeping the objectives of the present investigation in view, attempt has been made to present a very brief account of review on the effect of long term manuring on crop productivity and soil properties and a comprehensive review on selection and evaluation of soil attributes as indicators of soil quality and various methods for using them to develop quality indices on the following heads.

2.1 Effect on changes in soil properties
   2.1.1 Physical Properties
   2.1.2 Chemical Properties
   2.1.3 Biological Properties

2.2 Effect on crop grain yield

2.3 Effect on yield sustainability

2.4 Soil quality and its importance

2.5 Indicators/Attributes of soil quality

2.6 Indicator selection process

2.7 Assigning scores

2.8 Assigning weightages

2.9 Assessment of Soil Quality Index (SQI)

2.10 Relative Soil Quality

2.1 Effect on changes in soil properties

Long term experiments provide the best possible means of studying changes in soil properties and processes and identifying emerging trends in nutrient imbalance and deficiency and to formulate future strategies for maintaining soil health (Swarup, 2000). The changes in various physical, chemical and biological properties after 9 years of continuous manuring are discussed here.
2.1.1 Physical Properties

The soil physical condition controls several key functions in a given ecosystem that are important to biological processes and environmental stability. These include the capacity of the soil to retain and transmit water, provide energy and gas exchange, recycle nutrients, resist erosion and nutrient loss and over all, provide a hospitable medium for the growth of plant roots and beneficial soil microorganisms, insects and animals (Papendick, 1994).

In a long term study on Vertisols at Jabalpur, Kauraw and Sengar (2000) observed significantly improved aggregation in 100% NPK + FYM treatment followed by 150% NPK and poor aggregation in 100% N treatment. They also reported improved infiltration rate, hydraulic conductivity and bulk density, penetration force, moisture retention characteristics and pore size distribution with 100% NPK + FYM and 150 % NPK treatments. Other treatments registered only smaller changes over years.

2.1.1.1 Bulk Density

Continuous application of organic manure reduces the bulk density of soil. In India Nambiar (1994) reported that incorporation of FYM along with optimum dose of NPK for 7-13 years brought about a slight lowering of BD indicating improvement of soil physical properties. The treatment also recorded highest mean weight diameter of aggregates indicating appreciable improvement in soil structure. Application of nitrogen fertilizer alone slightly deteriorated the soil physical properties.

Chaudhary and Thakur (2007) revealed that FYM along with fertilizers had a positive effect on penetration resistance and bulk density of soil. Sharma et al., (2007) reported that bulk density of the soil in 100 per cent NPK + FYM plot was significantly lower than all other treatments which was attributed to the presence of highest amount of organic matter in the 100 per cent NPK + FYM treatment. In irrigated rice-rice system in Vertisols, Surekha and Rao (2009) found that bulk density ranged from 1.16 to 1.20 Mg m⁻³ in treatments where 1/3rd N was substituted through organic sources compared to 1.30
Mg m\(^3\) where recommended dose of NPK was applied through chemical fertilizers. The decrease in bulk density in these treatments was 8 to 11 per cent over recommended dose applied through chemical fertilizers. Therefore, the addition of organic matter to soil decreases the soil bulk density (Khan et al., 2006; Schjonning et al., 1994).

2.1.1.2 Water stable aggregates

In a long term study, Tripathi et al., (2014) reported that application of FYM along with inorganic fertilizers increased the proportion of macroaggregate (5–2mm) and meso aggregate (2–1mm) fractions as compared to application of inorganic fertilizer alone. Macro-aggregates had higher TOC and total N as compared to meso and micro-aggregates. Micro-aggregates had higher C/N ratio as compared to macro-aggregates. The results revealed that the accumulation of TOC and total N differed among different soil aggregates. The combined use of organic manure and inorganic fertilizers not only enhances the accumulation of SOC, but also improves the quality of soil organic matter by aggregation effect. Higher biomass accumulation, aggregate stability and MWD under NPK + FYM lead to greater soil organic carbon and nitrogen stabilization in aggregates. Similar results were also reported by Filho et al., 2002; Singh et al., 2007; Verma et al., 2010; Benbi and Senapati, 2010; Mahmood-ul-Hassan et al., 2013.

In a study Mikha and Rice (2004) found that an increased macro-aggregate content with higher inputs of fresh organic material is due to increased microbial activity and the production of microbial and fungal derived binding agents. Brar et al., (2015) shown that the addition of FYM and Zn as well as use of DAP instead of SSP as P source with 100% NPK significantly increased aggregate MWD compared to 100% NPK. Aggregate MWD increased significantly with increase in fertilizer application rate from 50% to 100% NPK, but no change in MDW from further addition of fertilizer to 150% NPK. In a study, Sharma and Biswas (1974) reported increased aggregate stability in acid soils following phosphate applications. This is attributed to the cementing action of Al and Fe phosphates, which are formed following phosphate application.
Wei et al., (2011) conducted an experiment on the size distribution of water-stable aggregates and the soil carbon, nitrogen and phosphorus concentration over aggregate size fractions based on a long-term (1990-2006) fertilization experiment in a reddish paddy soil. The results showed that the largest water-stable aggregate (WSA) (>5 mm) and the smallest WSA (<0.25 mm) took up the first largest proportion (38.3%) and the second largest proportion (23.3%), respectively. They also concluded that application of organic materials increased the proportion of the large WSA (>2 mm) and decreased the proportion of the small WSA (<1 mm), resulting in an increase in the mean weight diameter of WSA, whereas application of chemical fertilizer had little effect. In contrast, Li et al., (2010) conducted an experiment and showed that fertilization significantly increased soil nutrients, microbial biomass and enzyme activities but had no significant effect on soil aggregates.

2.1.1.3 Water Holding Capacity (WHC)

Malik et al., (2014) reported that the recommended dose of NPK showed higher value for water holding capacity than control at two depths. Tadesse et al., (2013) found that the application of 15 t ha\(^{-1}\) FYM increased the soil organic matter and available water holding capacity by about 2.16% and 17.6%, respectively, while it reduced the soil bulk density by 0.31 g cm\(^{-3}\). Bandyopadhyay et al., (2011) found that the surface layer (0–0.15 m) exhibited greater MWHC and AWC as compared to the sub soil, which could be ascribed to the presence of greater organic matter in the surface soil. Sharma et al., (2001) working on a rice-wheat cropping system revealed a marked increase in water holding capacity with integrated use of organics and fertilizers.

2.1.1.4 Hydraulic Conductivity

Saturated hydraulic conductivity (Ks) is a critical property affecting water and solute movement in soils. It is the proportionality constant which relates the amount of water which will flow through a unit cross-sectional area of aquifer under a unit gradient of hydraulic head per unit time. In general,
SOM is assumed to be positively correlated with $K_s$ because SOM can stimulate soil aggregation, which lowers bulk density, increases porosity, and hence elevates $K_s$ (Rawls et al., 2005) also showed that predicted $K_s$ values may be lower for elevated SOM content.

Bandyopadhyay et al., (2011) reported that saturated hydraulic conductivity ($K_{sat}$) decreased significantly ($P < 0.05$) with depth in all the treatments. This was probably due to increase in the compaction level in deeper layers, which reduced the effective pore volume in those layers. Cultivation without organics (i.e., control and NPK) caused a net decrease (48.3 and 31.1%) in $K_{sat}$ as compared to that in the fallow treatment. Such cultivation with NPK treatment, however, caused a net increase (33.3%) over the control. Increase in the root biomass as well as aggregation might be the causes of this increase.

Bellaki and Badanur (1997) reported that the hydraulic conductivity was highest in the treatment receiving 100% NPK + FYM (0.68-0.80 cm h$^{-1}$) and lowest in control plot (0.03 cm h$^{-1}$). The increase in hydraulic conductivity might be due to increase in soil organic matter content and subsequent increase in porosity of soil as a result of increase in soil aggregate size. Similar results were also reported by Bhatia and Shukla (1982) and Bellaki and Badanur (1997); Dinesh et al., (2009); Bajpayi et al., (2006); Zhe et al.,(2012); Han et al., (2010) ; Bhattacharyya et al., (2007); Khan et al., (2010).

Bandyopadhyay et al., (2010) reported that integrated nutrient management strategies decreased the bulk density (9.3%), soil penetration resistance (42.6%), and increased the hydraulic conductivity (95.8%), mean weight diameter of the water stable aggregates (13.8%) and soil organic carbon content (45.2%) compared to control. Sandhu and Singh (2001) reported that puddling decreased the percolation rate of water by up to 92% depending on the depth and intensity of puddling and soil texture.
2.1.2 Chemical Properties

2.1.2.1 pH

Soil pH is a single most important chemical property that influences many soil properties including nutrient availability. Soils vary in their buffering capacity for soil pH. Therefore management practices have varied influences on soil pH.

In a study on an acidic sandy loam Inceptisol at Bhubaneswar under rice-rice system, Majhi and Rout (2016) reported that continuous cropping without organic manure made the soil more acidic with a pH drop of 0.38-0.57 units within 9 years. Addition of FYM however, resisted this drop and maintained a more favorable soil pH with higher content of organic carbon and available nutrients.

Subehia et al., (2011) conducted a field experiment on an acidic silty clay loam soil Typic Haplustalf under rice-wheat cropping system and reported that the continuous cropping and fertilizer use in rice crop over the years decreased the soil pH marginally over initial value, except addition of organic manure and green manure. Addition of organics played a buffering role on soil pH which is evidenced by only 0.1 or 0.2 units increase/decrease in comparison to 100% NPK where soil pH decreased by 0.3 units after 17th cropping cycles. Prasad et al., (1983) reported that the rise in pH under FYM treatment was due to the deactivation of Fe$^{3+}$ and Al$^{3+}$ with concomitant release of basic cations (Ca$^{2+}$, Mg$^{2+}$ and K$^+$) during its decomposition. Rout et al., (2012) working on an acid soil also reported rise in pH over the initial value due to FYM and suggested for FYM to be used as a liming material for acid soils. In contrast Singh Brar et al., (2015) working on a Punjab soil found that addition of FYM showed no significant changes in pH compared to other fertilizer treatments except non-treated control.

Long term fertilizer experiments conducted in India also demonstrated no perceptible change in soil pH over the years in respect of soils with neutral to alkaline in reaction but the soil pH decreased by 0.9-1.0 units from the initial
values on two *Alfisols* (acidic pH) at Ranchi and Palampur under N treatment (Nambiar, 1994). Main (1990) found a severe leaching loss of basic elements Ca++, Mg++, Na+, K+ etc. from the soil in comparison to Fe++, Mn++, H+ and others.

Basumataray and Talukdar, (1998) in a long term experiment on integrated nutrient supply system in a rice-rice sequence indicated that continuous application of chemical fertilizer alone led to decrease in pH. The effect of fertilizer was more serious in *Alfisols* because of their poor buffering capacity (Singh *et al.*, 2010).

Benbi *et al.*, (2009) reported that declined in soil pH can have positive impacts on availability of nutrients such as phosphorus, zinc, iron and manganese. The availability of phosphorus is more in the pH range from 6.5 to 7.5. Use of urea fertilizer and build-up of organic matter might have resulted in decrease in pH.

Working on rice based cropping system; Devi (2002) found that the pH of bottom layers recorded a slight increase in pH with depth due to accumulation of more CaCO₃ in the bottom layers. Hati, *et al.*, (2008) found that the application of balanced fertilizer with lime increased the soil pH of the surface 15 cm soil from an initial value of 5.3 to 5.9, In the control and NPK treatment plots, a slight decrease in surface soil pH from the initial value was noticed. Similarly at 15–30 cm depth also, pH was highest in NPKL treatment. Sharma and Subehia, (2003) reported that decline in soil pH increases exchangeable aluminum content in soil and reduces crop yield in nitrogen fertilized plots. Mc Andrew and Malhi, (1992) reported that acidifications associated with N-fertilization also decreased microbial biomass C and N, and the amount of soil organic C and N.

### 2.1.2.2 Electrical conductivity (EC)

Dubey *et al.*, (2015) did not find any appreciable changes in EC over the years due to continuous fertilizer application in almost all the treated plots in a black soil. This could also be due to the peculiar characteristics of black soils.
that possessed inherent high buffering capacity which affected the slight alterations in EC of soil due to fertilizer addition as stated earlier by Sharma and Tripathi (1992) and Tomar (2003). Tripathi et al., (2014) reported that the addition of organics such as manure and inorganic fertilizer increased EC by adding cations and anions. A higher ECe was recorded in all the treatments compared to unfertilized control.

Hati et al., (2006) reported increase in soil EC with 100% NPK + FYM compared to non-treated control and other fertilizer treatments over a period of 28 years in soybean-wheat-maize rotation.

Tuyen (2013) used a long-term experiment that commenced in 1986 to examine the effect of nitrogen (N), phosphorus (P) and potassium (K) applications after 34 consecutive crops in intensive rice–rice system at CLRRI, Vietnam. In the surface soil, EC ranged from 0.20 to 0.26 mS cm\(^{-1}\) which did not limit rice growth. Nevertheless, EC values of all treatments declined compared to the initial EC value (0.74 mS cm\(^{-1}\)). This suggests that after cultivating two crops per year, the irrigation decreased the soluble salt concentration. In control plot, EC was lower than those supplied with fertilizer. This indicates that fertilizer increases the salt concentration in soil, but not to a harmful extent.

Chaudhari et al., (2013) found in the soils of north Maharashtra region that electrical conductivity showed a positive correlation with N and P but without significance. The result also showed significant correlation between electrical conductivity and K. The application of fertilizer nitrogen reduced the release rate of K, whereas the incorporation of manure, with fertilizers, increased it over the values obtained from soil collected on the onset of the experiment (Singh et al., 2001). It has been observed that organic matter of the soil bears a positive correlation with the availability of K (Verma and Verma, 1968). The reason is organic matter increases the cation exchange capacity and exchangeable cations. The transformation of organic matter in relation to K availability was studied by Debnath and Hazra (1972). It was observed that as a supplier of K to crops, the efficiency of various organic material would be graded as straw > dhanicha > FYM.
2.1.2.3 Cation exchange capacity (CEC)

Sepehya, (2011) conducted a field experiment on a silty clay loam soil *Typic Haplustalf* under rice-wheat cropping system and reported that application of chemical fertilizers either alone or in conjunction with organic materials increased CEC of the soil significantly over control. Application of 100 per cent NPK alone registered an increase of 20.3 per cent over control. The CEC values under integrated use of organics and chemical fertilizers were significantly higher than control but were statistically at par with that observed under 50 and 100 per cent NPK alone. Amongst the treatments consisting of different organic sources, the plots which received FYM recorded higher CEC followed by wheat cut straw and green manure. Singh Brar *et al.*, (2015) found that 150% NPK treatment maintained highest CEC which was 14% higher than 100% NPK + FYM.

In another study Subehia *et al.*, (2011) found that cation exchange capacity (CEC) increased significantly in all the treatments except 50% NPK. Maximum increase in CEC (25%) over control was observed in treatment receiving 50% NPK+50% N through FYM to rice followed by 100% NPK to wheat. Similarly, wheat cut straw and green manure also improved CEC of soil when applied in conjunction with chemical fertilizers. All the organic sources were equally effective in influencing CEC of soil. This increase is ascribed to formation of humus on incorporation of organics which provided a store house for exchangeable cations viz, $K^+$, $Ca^{2+}$, $Mg^{2+}$ etc. (Phogat *et al.*, 2004). Verma *et al.*, (2010) from a maize-wheat cropping system revealed that after continuous cropping for nine years, CEC increased in all the treatments over control. However, larger increase in CEC was observed in soil which received nutrients in balanced and integrated form.

2.1.2.4 Soil Organic Carbon (SOC)

In a study on an acidic sandy loam *Inceptisol* at Bhubaneswar under rice-rice system, Majhi and Rout (2016) suggests that application of recommended dose of NPK fertilizers over years increases the SOC content
and with inclusion of FYM @ 10t ha\(^{-1}\) per year or sulphur@30 kg ha\(^{-1}\) or increase in NPK level by 50\% over optimal dose, there is further increase in SOC.

Soil organic carbon (SOC) levels are directly related to the amount of organic matter contained in soil. SOC levels result from the interactions of several ecosystem processes, of which photosynthesis, respiration, and decomposition are the keys. SOC input rates are primarily determined by the root biomass of a plant, but also include litter deposited from plant shoots. Soil carbon results both directly from growth and death of plant roots, as well as indirectly from the transfer of carbon-enriched compounds from roots to soil microbes (Ontl and Schulate, 2012). Maintenance of soil organic carbon is essential for long-term sustainable agriculture, since declining levels generally lead to decreased crop productivity (Allison, 1973). SOC is an important index of soil quality because of its relationship to crop productivity (Campbell et al., 1996; Lal et al., 1999). Long-term experiments are the primary source of information to determine the effect of cropping system, soil management, and fertilizer usage and residue utilization on changes in soil organic carbon (SOC) and to determine agricultural sustainability.

Results of Long Term Fertilizer Experiments conducted at Ludhiana, Hyderabad, Bhubaneswar, Palampur and Coimbatore also showed increase in organic matter contents due to intensive cropping (Nambiar and Ghosh, 1984). In a more recent study Md. Mehedi Hasan et al. (2009) reported that the status of organic matter increased over initial value due to fertilization and cropping for the last 29 years and the increase of organic matter was higher in FYM plot. The reason of increase in organic matter status in soil than initial is due to the increase in crop bio mass production with fertilization. Results from a few long term experiments also showed similar build up of SOC due to application of manure with balanced fertilization (Tripathy et al., 2014; Rudrappa et al., 2006). Manna et al., 2007 observed that application of fertilizer NPK, either alone or in combination with FYM maintained active or slow release pools of C, sequestered C and improved soil qualities and productivity.
Devi (2002) recorded a marked increase (0.4 to 0.6 units) in SOC content over the years (1988-2001) from the initial value of only 0.27%. Surprisingly, the experimental site (vertic Haplaquepts) at Keonjhar with high rainfall (1500-1600mm) and high temperature (35-40°C) had exceedingly high organic carbon enrichment within 13 years. Organic carbon content varied from a lowest of 0.67% in the unfertilized control to a highest of 0.84% in the 100%NPK+FYM treated plot. The 100%N treatment had relatively small enrichment of SOC (i.e. 0.68%). The lower enrichment in control and 100%N treatment is due to addition of smaller volume of biomass through roots every year.

Yang et al., (2004) observed that the total C in paddy soil was 40–60% higher in the combined organic sources and inorganic fertilizers treatment against the inorganic fertilizers alone treatment. Elayarajan et al., (2015) reported that continuous application of organic manures either singly or in combination with inorganic fertilizers maintained higher organic carbon content than inorganic fertilization alone.

SOC content increased with application of Zn due to the same reason (Prasad et al., 2010). Combined application of micronutrients like B with Zn however, did not have any significant effect on SOC which is due to addition of lesser biomass (Balu Ram et al., 2014, Singh et al., 2012, Majhi, 2001). But application of S along with Zn had positive effect on SOC (Singh et al., 2012).

Kumar and Singh (2010) reported that after six cycles of rice-wheat, incorporation of green manures with and without FYM along with 100 per cent NPK significantly increased the organic carbon content. On the other hand, 100 per cent NPK through mineral fertilizers alone could not maintain initial status. In the long-term field experiments, at Ludhiana (Ustochrept), Hyderabad and Bhubaneswar (Tropaquept) and Palampur (Hapludalf) cultivation for 15 years increased soil organic carbon. The increase was most distinct with laterite soils of Bhubaneswar (Prasad and Gowswami, 1992).
2.1.2.5 Available and total Nitrogen

Mengel and Kirkby, (1987) concluded that nitrogen (N) is the fourth plant nutrient taken up by plants in greatest quantity next to carbon, oxygen and hydrogen, but is one of the most deficient elements in the tropics for crop production. They also stated that total N content of a soil is directly associated with its SOC content and its amount on cultivated soils is between 0.03% and 0.04% by weight.

Tisdale et al.,(1995) reported that N content is lower in continuously and intensively cultivated and highly weathered soils of the humid and sub humid tropics due to leaching and in highly saline and sodic soils of semi arid regions due to low OM content. Continuous application of nitrogen (N) resulted not only in lowering of soil pH but also deficient of both phosphorus (P) and potassium (K) in the soil.

Elayarajan et al., (2015) in a recent study showed that continuous application of either organic or inorganic fertilizers or in combination increased the available N content of soil. Higher value was recorded in the treatment that received integrated application of 100% inorganic fertilizers along with FYM @12.5 t ha\(^{-1}\). The increase in available N content with the incorporation of organic sources is attributed to N mineralization from organic sources (Sharma et al., 2008). The lowest value was noticed in control. Continuous removal by crops without external addition of fertilizers and FYM over a period resulted in decline in soil available N.

Moharana, et al., (2012) also reported similar results. The increase in KMnO\(_4\)-N in FYM amended plots is attributed to the increase in total SOC and might have been partially due to a slow release of N from manure. Farmyard manure is known to stimulate biological N\(_2\) fixation in the soil, which may also have been responsible for the increase in soil N (Ladha et al., 1989) over NPK treatment, apart from FYM’s own N contribution. In addition, soils under NPK + FYM treated plots produced more biomass and, therefore, possibly had more extensive root systems that may have contributed to increased N levels. In a
recent study Bhattacharyya et al., (2015) also reported higher carbon and nitrogen content under 100%NPK + FYM treatment. This can be due to continuous incorporation of larger amounts of carbon through roots and stubbles in to soil (Srilatha et al., 2015) and increased microbial population and enhanced mineralization (Muthuvel et al., 1977).

Majhi (2001) reported that continuous application of organic materials or their integration to an acid Inceptisol planted to rice-rice cropping increased the content of total N to a large extent and mineralizable N to a small extent but there was decrease in soil organic carbon content. Patnaik (2012) working on an acid Inceptisol of rice-rice cropping at Bhubaneswar, observed that in 100% NPK+FYM treatment , the available N content considerably showed an increase of 20% over the initial value. In other treatments, the increase in N availability ranged between 4 and 19 %. However, it decreased in the control by 26%.

Devi (2002) reported a marginal increase (10-20kg ha\textsuperscript{-1}) in the available N (alkaline permanganate) in the cropped soil over the initial value Application of FYM stimulated the availability of N and registered higher value. However, there was no significant difference among other treatments.

Dubey et al., (2015) reported highest N content in 100% NPK+FYM treatment followed by 150% NPK which was due to better biological activities in presence of FYM. Addition of N either through fertilizer or through FYM enriched the total N pool of the soil. Although there was continuous removal of N in control plot it was at par. This might be due to continuous addition of N through other sources like biological N fixation (Rangaswamy and Venkataraman, 1996). Singh et al., (2012) reported the available N status of soil was affected significantly due to application of sulphur and zinc.

Manna and Ashraf (2000) reported organic manures increased soil organic matter content and total nitrogen. Yang et al., (2004) observed that total N in paddy soil was 37–67% higher in the combined organic sources and inorganic fertilizers treatment against the inorganic fertilizers alone treatment.
Mandal et al., (2009) reported that increase in soil organic C, total N and available N levels due to long term application of S and manures with balanced NPK. One of the major reasons for such observations is greater input of root biomass due to better crop productivity. Interaction effect of treatments (e.g., NPK + FYM) and rhizosphere conditions induced by plant growth stages (e.g., tillering) played a major role in the enhancement of nutrient availability (e.g., mineralizable N).

Zn application increased N concentration and uptake by increasing root development and N use efficiency. Nitrogen uptake and concentration were not increased by the application of lower N rates reported by Salam and Subramanian (1988). Whereas Masthana reddy et al., (2009) reported that the application of P up to 55 kg ha\(^{-1}\) in kharif and up to 44 kg ha\(^{-1}\) in summer recorded higher N-recovery (36.2 and 40.9% in kharif and summer, respectively) and agronomic efficiency (11.0 and 20.1kg grain kg\(^{-1}\), N respectively during kharif and summer). Potassium at different levels ranging from 62 to 104 kg ha\(^{-1}\) had no significant effect on N-use efficiency.

Ali et al., (2009) reported that application of organic manure and crop residue with chemical fertilizer increased the organic matter, total N, available P, available S and exchangeable K contents of soil. The organic matter status was considerably improved due to the application of organic manure or crop residue. The increase in total N might be due to the direct addition of N through organic manure added to the soil.

2.1.2.6 Available and total Phosphorus

Verma et al. (2005) studied the effect of continuous cropping and fertilization on nutrient status of a Typic Haplustept. They revealed that after two years of experimentation significant increase in available P content was recorded by applying 100 per cent NPK + FYM @ 10 t ha\(^{-1}\) and 150 per cent NPK. Graded levels of P application were accompanied by a corresponding increase in the amount of available P owing to higher rates of P application in the amount exceeding crop uptake (Santhy, et al., 1998). The available P status of soil after 10 years of rice–wheat cropping was minimum in control whereas the maximum available P was found in NPK + FYM + Zn treatment.
Moharana, et al., (2012) reported that the increase in Olsen-P in plots receiving FYM applied either alone or in combination with NPK possibly due to release of organically bound P during decomposition of organic matter, solubilization of soil P by organic acids produced during decomposition of organic matter. The application of FYM increased Olsen-P because of its P content and possibly by increasing retention of P in soil. A positive effect of FYM on P availability was also observed by Roy et al., (2001). This might be due to the fact that the major P fraction added through FYM is in the organic pool, which mineralized slowly with time (Yadvinder-Singh et al., 2004). Increase in Olsen-P in NPK fertilizer is due to residual effect of higher amount of fertilizer P applied annually in this treatment as compared to no application of fertilizer in FYM and low application of fertilizer P in FYM + NPK treated plots.

Biswa and Benbi (1997) reported considerable build-up of Olsen-P with application of phosphatic fertilizer, while those not receiving phosphatic fertilizer annually have shown a decline in Olsen-P. Similarly, earlier reports suggested that long-term application of P fertilizer in excess of crop requirement can build-up large amounts of P in soil in both the inorganic and organic pools (Singh et al., 2007).

Devi (2002) reported that in all the P treated plots there was built-up of total P. This agrees with the results reported by Sahoo et al., (1998); Swarup (2000). According to Foth and Ellis, (1997) P is known as the master key to agriculture because lack of available P in the soils limits the growth of plants. Where crop residues are returned to the soil, an increase in P availability may occur by decreasing the adsorption of P to mineral surfaces (Ohno and Erich, 1997).

Subehia et al., (2011) found that buildup of available P with the application of chemical fertilizers with organics. Increase in available P of the soil with the use of recommended dose of NPK may be attributed to lower utilization of P from the applied sources.
A build-up of P in P-receiving plots and depletion in N and K treated plots was also reported by Ghosh, et al., (2000). In calcareous soil, CO$_2$ produced during the decomposition of organic matter plays an important role in increasing the phosphate availability. Organic matter enhanced the labile P in soil through complexation of cations like Ca and Mg when it is applied in combination with inorganic fertilizers (Tolanur, et al., 2003). Among the treatments, 100% NPK + FYM recorded the highest level of P availability in the surface layer of soil in LTFE (Inceptisol). Also the addition of 150 per cent of NPK had shown a beneficial effect. Phosphorus availability was found to increase with increase in the amounts of applied NPK in the 0-15 and 15-30 cm layers (Santhy, et al., 2002). Similarly application of FYM also resulted in built up of available P and available K. The effect of FYM being a direct source of P availability could have also solubilised the native P in soil through release of various organic acids (Das et al., 1991).

Shai Ram et al., (2016) working on a silty clay loam hyperthermic Aquic Hapludoll under humid subtropical climate reported that continuous application of FYM in combination with inorganic fertilizers showed significantly greater organic carbon and N, whereas the super optimal dose of inorganic fertilizers (150% NPK) gave significantly greater P and K over other fertilizer treatments. Results also revealed that long-term application of super optimal dose of fertilizers could maintain the greatest levels of P and K, which were found to be comparable to integrated nutrient-management practice. The addition of 50% extra dose of P and K did not have much influence on the availability of P and K compared with 100% NPK +15 t FYM ha$^{-1}$. The slight increase in available P owing to the super optimal dose of fertilizers might be due to only 25–30% availability of applied P to crops and the rest is fixed in soil (Urkurkar et al., 2010), whereas application of FYM may solubilize the native P at a greater rate in soil through the release of various organic acids under irrigated conditions (Tiwari 2003). Also, organic ions compete with the phosphate ions for binding sites on soil particles, thereby reducing the P fixation (Panneerselvam, Lourduraj, and Balasubramanian, 2000).
In a 42 year long term fertilizer experiment, it was observed that under low- and high-input treatments, yield as well as P uptake was maintained at constant levels for 35 years. The Fe–P fraction was highest compared to the Ca–P and Al–P fractions after 42 years of fertilizer application and was significantly higher under FYM + NPK treatment. The P adsorption capacity of soil was highest under the low-input treatment and lowest under long-term balanced fertilization (FYM + NPK). In contrast, P desorption capacity was highest under NPK and lowest in the control treatment. Long-term balanced fertilization in the form of FYM + NPK for 42 years lowered the bonding energy and adsorption capacity for P in soil but increased its desorption potential, increasing P availability to the plant and leading to higher P uptake and yield maintenance (Bhattacharyya et al., 2015).

2.1.2.7 Available, total and 1NHNO₃ Potassium

Many studies conducted under long term fertilizer experiments with various cropping systems have revealed that treatments with 100% NPK +FYM and 150%NPK showed more available and exchangeable K in soil. In a study at Bhubaneswar, Patnaik (2012) observed highest increase is available in 150% NPK treatment whereas the lowest in the control. Rice roots could increase the solubility and availability of potentially available K and even mineral-K in the rhizosphere under submerged condition (Yang et. al., 2005). The increase in available K content of soil with the application of 100%NPK along with FYM may be explained by mineralization of organic matter and solublisation from native source arising during decomposition (Mazumdar et al., 2014). With inputs of organic materials, a greater rate of soil reduction is expected, and through greater root-induced acidification this would cause greater mobilization of non-exchangeable K (Wihardjaka et al., 1999). In contrast, Singh et al., (2012) reported that the available K status of soil was affected significantly due to application of sulphur and zinc.
Devi (2002) working on a vertic Haplaquept showed an increase in available K status in cropped land over 13 years from an initial value of 144 kg ha\(^{-1}\). The treatment with 100\%NPK+FYM registered highest content (260 kg ha\(^{-1}\)) of available K. The positive effect of FYM on K built-up has also been reported by many workers. Results on 1N HNO\(_3\)-extractable K reveal that reserve K varied from a lowest of 309 kg ha\(^{-1}\) observed in 100\%NPK treatment to a highest of 400 kg ha\(^{-1}\) in the treatment that received NPK+FYM. The results demonstrate the significant contribution of FYM to preventing the mining of reserve K (Sahoo et al., 1998). The application of fertilizer Nitrogen reduced the release rate of K, whereas the incorporation of manure, with fertilizers, increased it over the values obtained from soil collected on the onset of the experiment (Singh et al., 2001). It has been observed that organic matter of the soil bears a positive correlation with the availability of K (Verma and Verma, 1968). The reason is, organic matter increases the cation exchange capacity and exchangeable cations. The transformation of organic matter in relation to K availability was studied by Debnath and Hazra (1972). It was observed that as a supplier of K to crops, the efficiency of various organic material would be graded as straw > dhanicha > FYM.

In a recent study Elayarajan et al., (2015) reported that integrated application of 100\% NPK + FYM resulted in the highest value of available K. The increase in the availability of K through addition of FYM may be due to the decomposition of organic matter and release of nutrients. The beneficial effect of FYM on the available K is also due to the reduction of K fixation and release of K due to interaction of clay with organic matter (Kamble and Kathmale, 2012). The decreased availability of K in control may be attributed to the higher uptake of K by crops resulting in depletion of K in the absence of K addition.

Selvakumari (1981) observed increase in exchangeable K for continuous application of manures. The beneficial effect of organic manuring on K availability was due to minimizing the losses through leaching by retaining K
ions on exchange site, solubilisation of insoluble components through the action of organic acids released during decomposition and minimizing losses due to fixation in 2:1 minerals. In India there is also evidence in many centers (Bhubaneswar and Jabalpur) that the crop starts using the non exchangeable K when the exchangeable K amount falls below the critical limits (Swarup, 2000).

Moharana et al., (2012) reported that application of FYM resulted in an increase in NH$_4$OAc-K due to more release of non-exchangeable K from the soil as FYM increased soil cation exchange capacity, which might have resulted in increased NH$_4$OAc-K and its utilization by crops (Blake et al., 1999), besides FYM’s own K supply.

The long-term effect of application of micronutrients on the available K status of the soil was studied and it revealed that the application of micronutrients alone decreased the available K status of the soil whereas the application of these nutrients along with FYM increased its availability (Vyas et al., 2003).

Potassium (K) solubilizing bacteria are able to release potassium from insoluble minerals (Sugumaran and Janarthanam et al., 2007). In addition, some researchers (Lian et al., 2002, Bosecker, 1997) have discovered that K-solubilizing bacteria can provide beneficial effects on plant growth through suppressing pathogens and improving soil nutrients and structure. For example, certain bacteria can weather silicate minerals to release potassium, silicon and aluminum, and secrete bio-active materials to enhance plant growth. Sudipta et al. (1996) also observed that significant increase of paddy yield and K uptake in grain with increasing levels of K fertilization. Supplementation of Zn caused further increase in yield as well as K uptake and indicated positive Zn x K interaction.
2.1.2.8 Available Sulphur

Sulphur which is now considered as the 4th primary nutrient has become deficient in many intensively cropped zones and more importance is now given for its management in different crops.

In a study Reddy et al., (2004) reported that intensive cropping with continuous use of 100 per cent NPK without S resulted in depletion of total, organic and inorganic sulphur content by 18.1, 17.8 and 21.7 per cent, respectively, over control in a long-term cropping with different fertilizer and organic inputs in a Typic Haplustert. The distribution of different forms of sulphur was observed in decreasing trend with depth in both Inceptisols and Vertisols. Higher amounts of total sulphur in surface than in sub-surface soils resulted from its recycling over the years by plants and subsequent organic matter accumulation. Organic sulphur in the soils accounted for 59 and 62 per cent in Inceptisols and Vertisol, respectively. The average organic sulphur values were higher in Vertisol than in Inceptisol at surface and decreased with depth (Bhatnagar and Trivedi 2005).

Moharana, et al., (2012) reported that increase in CaCl₂ extractable (available)-S in surface soil depth was 68.2 and 61.4% in FYM + NPK and FYM treated plots over control. This increase is attributed to the addition of sulphur through FYM. Sarkar et al., (1998) reported that application of various organic sources like compost, FYM, green manure and crop residues can supply adequate quantities of sulphur to crops. Nambiar and Abrol (1989) also reported from the long-term fertilizer experiments conducted at several locations that the treatment involving un-interrupted yearly application of FYM could maintain adequate status of sulphur to guard against its deficiency in soils.

Singh et al., (2012) reported a significant positive interaction of sulphur and zinc in presence of NPK fertilizers under continuous rice-rice system.
2.1.2.9 Available Zinc

The studies carried out at IRRI (2000) indicated that under severe Zn deficiencies, tillering in rice decreased or could stop completely, and time to crop maturity increased. Zn deficiencies could also increase spikelet sterility in rice. Zinc removal by rice ranged from 0.04 to 0.06 kg Zn t\(^{-1}\) of grain yield, with an average of 0.05. A rice crop yielding 6 t ha\(^{-1}\) takes up about 0.3 kg Zn ha\(^{-1}\), of which 60% remains in the straw at maturity (IRRI, 2000). Similarly many workers reported increases in uptake of Zn by rice plants with Zn application (Nand and Ram, 1996), Rajan, 1993 and Maharana et al., 1993)

Maximum zinc content under all the treatments was observed at active tillering stage. With advancement in age, the zinc concentration in plant declined. Zinc application in nursery gave maximum concentration of zinc in the treatment of root dipping in ZnO suspension irrespective of zinc application in transplanted field at all the stages. Under transplanted condition, the similar trends were observed with little variation (Kumar and Singh, 1979).

Kaur et al., (1985) also opined that zinc concentration in all the plant parts increased up to 30 days after transplanting and decreases thereafter with rate of decrease being much faster from 30 to 45 days than from 45 to 60 days. Takkar (1996) reported that harvest of 8.0 t grain ha\(^{-1}\) yr\(^{-1}\) removed 320 and 384 g Zn ha\(^{-1}\) yr\(^{-1}\) in rice–rice and rice-wheat cropping systems.

Zinc deficiency is widely reported in flooded rice (Singh and Abrol, 1986b) and wheat due to slow release of Zn from soil organic matter complex, as well as restricted root growth in the winter season leading to lower uptake of Zn by plants. Pal et al., (1997) reported that DTPA extractable zinc ranged from 0.9 to 3.0 mg kg\(^{-1}\) soil which constituted only about 1 per cent of the total zinc content in the rice growing soils (Haplustalf) of Orissa. Zinc present in soil solution and in exchangeable form is generally a very small fraction of the Zn and it may be specifically adsorbed, non- specifically adsorbed organically bound, Mn- oxide bound, Al and Fe- oxide bound or held in some other way (Iyenger et al., 1981). Pal et al., (2002) found DTPA extractible Zn content varied from 0.98 to 3.78 mg kg\(^{-1}\) in rice grown soils of Odisha, and positively correlated with silt, organic carbon but negatively with pH.
Prasad (2010) and Singh (2008) reported 49% of Indian soils deficient in Zn and Jena et al., (2008) reported that about 19% of the Odisha soils are deficient with Zn content ranging from 0.24 to 2.08 mg Kg\(^{-1}\) with mean value of 1.10 mg kg\(^{-1}\). Soils formed from parent materials such as quartz sand contain low total and available Zn and highly prone to Zn deficiency. The occurrence of CaCO\(_3\) in coarse textured soils with low organic matter contents limits the availability of Zn in soil (Singh and Abrol, 1985).

Sajwan and Lindsay (1988) observed the cause of Zn unavailability in flooded rice soil. They clarified that flooding and submergence bring about a decline in Zn availability because of the change in pH value and formation of insoluble Zn compounds. Zinc compounds formed are likely to be with Mn and Fe hydroxides. Under the submerged conditions in rice cultivations, Zn is transformed into amorphous sesquioxide precipitates on franklinite; ZnFe\(_2\)O\(_4\).

Results of long term studies conducted in India demonstrate that addition of FYM in optimum quantity has synergistic effect on improving the efficiency of optimum doses of NPK and correcting deficiency of Zn and S in most cases (Singh and Swarup, 2000). Build up of available Zn due to organic matter application has been reported by several workers (Sakal et al., (1997); Singh et al., 1998). Prasad et al., (2010) reported that the buildup of Zn occurs through organic matter addition and/or exploitation of native Zn by chelation through decomposition product of organic matter. Singh (2001) reported that mean concentration of DTPA extractable Zn varied from 0.1 to 6.92 mg k\(^{-1}\) in most Indian soils, with a mean of 0.87 mg Zn k\(^{-1}\).

Shah and De Datta (1991) reported that application of Zn at 10 kg Zn ha\(^{-1}\) was sufficient to correct Zn deficiency in rice although the highest grain yield was obtained with 40 kg Zn ha\(^{-1}\). Modest S response was recorded with 25 kg S ha\(^{-1}\) application when 40 kg Zn ha\(^{-1}\) was applied together with S. In contrast, high S levels beyond 25 kg S ha\(^{-1}\) decreased grain yield when it was applied with Zn.
In a 13 year long term study, Devi (2002) found that available Zn measured in all treatments including control were more than the critical soil level i.e. 1.2 kg ha\(^{-1}\) and not a constraint to crop production. However the yield increase in Zn treated plot might be due to the favorable effect of Zn on bacterial activity (Rout, 2001).

Mishra and Singh (1996) reported that high B supplies caused low uptake of Zn and Zn deficiency enhanced B accumulation and Zn fertilization reduced B accumulation and toxicity on plant grown in soils containing adequate boron. Application of B increased the availability of all nutrients, while the application of Zn especially at higher level (5.0 kg Zn ha\(^{-1}\)) decreased the availability of Cu and Fe. Krishnamoorthy and Krishnamurthy (1978) concluded that zinc fertilization enhanced the uptake of N and K by popular rice varieties, however, higher levels of zinc depressed phosphorus uptake while lower levels favored its absorption.

Yang et al., (2009) in a research reported that the combined application of boron with molybdenum or zinc resulted in higher rapeseed yield and quality than the application of boron with molybdenum or zinc alone, and the seed yield of the B + Mo + Zn treatment was the highest in all treatments.

Singh et al., (1999) reported that there was reduction in the content of DTPA-Zn after ten years of continuous cropping where the plots did not receive these nutrients either directly or through FYM in rice-wheat cropping system. However, there was overall increase in the DTPA extractable Cu, Mn and Fe during the period in the plots treated with single super phosphate and/or FYM.

Sakal et al., (1997) reported that the continuous rice-wheat system with increasing NPK fertilizer application is the cause of depleting the soil available micronutrients reserve, particularly available zinc, leading to decline in crop productivity.
Behera et al., (2008) reported that in an Inceptisol under long-term maize-wheat cultivation DTPA-Zn concentration in soil was higher where Zn had been applied and declined with increase in depth. Residual Zn was the dominant portion of total Zn at all soil depth and zinc associated with easily reducible manganese, carbonate and iron and aluminum oxides contributed directly towards DTPA-extractable Zn. Mishra et al., (2009) reported that combined use of 100 per cent NPK + FYM resulted in higher content of copper acetate-extractable as well as pyrophosphate-extractable Zn which could be attributed to favorable soil pH and presence of higher organic matter content while the highest content of CBD-extractable Zn was found in the unfertilized fallow soil which could be attributed to higher content of crystalline oxides in the undisturbed soil.

In a field study conducted on the effect of the continued manuring on the extractable micronutrients in an Alfisol, DTPA-extractable Zn content was found to be higher in 100% NPK + Zn treatment and 100% NPK + FYM treatment (Hemalatha et al., 2013). The increase in Zn content due to the application of FYM was due to the mineralization of organically bound forms of Zn in the FYM and possible addition of Zn through super phosphate. Kumar and Singh (1979) reported that sulphur application at higher levels decreased the Zinc concentration in leaves, pod, husk and grain of soybean.

2.1.2.10 Available Boron

Next to Zinc, Boron is one of the essential micronutrients required for normal growth and development of plants. Boron is associated with calcium utilization, cell division, flowering and fruiting, carbohydrate and catalyst for certain reaction (Sprange, 1951). The hot water soluble boron content in soils of Odisha ranged from 0.18 to 5.1 mg kg\(^{-1}\) with mean value of 1.41 mg kg\(^{-1}\) with 44% of Odisha soils deficient in boron (Jena et al., 2008).
Suresh (2012) observed B accumulation was from 18.37 to 27.26 ppm in straw and 13.51 to 19.22 ppm in grain respectively. Boron accumulation was more in root than straw and grain i.e. B could not move from root to grain. It may be due to limited use of organic matter, light textured, acidic soil receiving heavy rain fall and adsorption of B by Fe and Al-oxides in lateritic soil. Panhwar et al., (2011) reported that concentration of B and Zn in plant tissues and its uptake were higher at the higher rates of applied fertilizers. An antagonistic effect was found for B uptake with higher levels of B and 5 kg ha\(^{-1}\) of Zn. On the other hand a synergistic effect was found for Zn uptake at 0.5 kg ha\(^{-1}\) of boron.

Mishra and Singh (1996) reported that high B supplies caused low uptake of Zn and Zn deficiency enhanced B accumulation and Zn fertilization reduced B accumulation and toxicity on plant grown in soils containing adequate Boron.

2.1.3 Biological Properties

Management practices tremendously influence the microbial population, microbial density, microbial biomass, microbial respiration and enzyme activities.

2.1.3.1 Soil Enzymes

2.1.3.1.1 Dehydrogenase Activity

Burns (1978) found that the dehydrogenase activity is commonly used as an indicator of biological activity in soils. The respiration pathways of soil organisms are closely related to the type of soil and soil-water conditions (Dolemen and Hanstra, 1979; Kandeler et al., 1996 and Glinksji and Stepnierski, 1985). Since these processes are part of respiration pathways of soil micro-organisms, studies on the activities of dehydrogenase is very important as it may give the indication of the potential of the soil to support bio-chemical processes which are essential for maintaining soil fertility. Ryoichi et al., (2009) reported dehydrogenase activity to be a good indicator of soil degradation.
Benkiser et al., (1984) showed that higher doses of K had detrimental effect on enzyme activity. Dehydrogenase activity decreased with increased supply of K. This is also supported by the findings of Devi (2002). Addition of Fe$_2$O$_3$, Mn$^{2+}$, SO$_4^{2-}$, PO$_4^{3-}$ and Cl$^{-}$ stimulated soil dehydrogenase activity whereas NO$_3^-$, NO$_2^-$, Fe$^{3+}$ seemed to inhibit this activity. (Bremner and Tabatabai, 1973).

Tripathi et al., (2007) found that higher soil dehydrogenase activity in the warm season than in the cool season, but the hydrolytic enzyme activities of soil were similar in summer and winter season. Lard and Paul, (1973) reported increase in the dehydrogenase activity with increase in organic matter content and microbial population of soil. The dehydrogenase activity was less in treatments receiving inorganic N which could be attributed to the presence of nitrate and nitrite that serve as alternate electron acceptors. Nitrate and nitrite are also obviously formed on transformation of urea in soil. Benckiser et al., (1984) showed that higher doses of K alone had detrimental effect on enzyme activities. Dehydrogenase activities decreased with increased supply of K.

Sridevi et al., (2012) reported that the activity of dehydrogenase was significantly higher with organic nutrient management practice throughout the crop growth period. The increased dehydrogenase activity might be due to incorporation of organics and owing to increase in microbial activity of the soil (Nannipieri, 1994). Similar results were also reported by Pauscal et al., (1998). In a pot experiment on rice crop (without rice crop-control) application of FYM @ 22.32 g kg$^{-1}$ soil recorded highest activity of 3 enzymes at 60 DAT. Urease activity was 14 fold, acid phosphatase activity 8 fold and alkaline phosphatase 11 fold.

Pauscal et al., (1998) reported that interaction effect proved the validity of treatment 150% NPK + 12.5t composted coir pith/ha in recording the highest dehydrogenase activity which was due to incorporation of organics and increase in microbial activity of the soil.
In a study on an acidic sandy loam Inceptisol at Bhubaneswar under rice-rice system, Majhi *et al.*, (2016) reported lower dehydrogenase activity in soils that continuously received NPK fertilizers and higher in control and highest in soil that received 100% NPK + FYM @10t ha\(^{-1}\) yr\(^{-1}\). The increased dehydrogenase activity in organic manure applied soil might be due to incorporation of organics and owing to increase in microbial activity of soil (Nannipieri, 1994; Sridevi *et al.*, 2012). It weakly correlated with SOC content (r =0.19). Unmanured control plot also had significantly higher dehydrogenase activity than many of the fertilized treatments which either received 50% more NPK or which received Zn or Zn + B or Zn + S. Between B and S, the latter had greater positive impact on dehydrogenase activity. Increase in dose of NPK to 150%, significantly decreased the dehydrogenase activity. This might be due to over dose of K (150%) that had adverse effect on dehydrogenase activity due to relatively high available K reported (Patnaik, 2012). Supporting this Devi, (2002) in a similar study reported that higher level of available K caused reduction in fungi population and Mohanty (2015) experimenting on the same soil reported negative impact of Zn and K on algal population which might be a reason for reduction in dehydrogenase activity. In 100%NPK +FYM treatment, the negative impact of K was counteracted by 10t FYM resulting in more microbes and higher dehydrogenase activity.

2.1.3.1.2 Acid Phosphatase

Phosphatases are a broad group of enzymes that are capable of catalyzing hydrolysis of esters and anhydrides of phosphoric acid (Schmidt and Lawoski, 1961). In soil ecosystem these enzymes are believed to play critical roles in P-cycles (Speir and Ross, 1978). Apart from being good indicators of soil fertility, phosphatase enzyme plays key roles in the soil system (Dick and Tabatabai, 1984; Eivazi and Tabatabai, 1977 and Dick, 1994).
Phosphatase activity increased with added C suggesting that soil organic carbon is a limiting factor for P mineralization (Wang Liang et al., 2010). Thirty percent increase in alkaline phosphatase activity has also been reported by Zhao Limei et al., (2009). Application of organic fertilizer significantly increased urease and phosphatase activities. Phosphatase activity was at its peak from 30-60 days after planting (Wang Fei Xiang et al., 2011). Similarly the activity of acid and alkaline phosphatases correlated with organic matter in various studies (Guan, 1989; Jordan and Kremner, 1994 and Aon and Coloneri, 2001). It was also found that combined application of 150% NPK along with composted coir pith @12.5 t ha\(^{-1}\) was most efficient in increasing the phosphatase activity by recording 12.25 mg P-nitrophenol kg\(^{-1}\) soil h\(^{-1}\) in 100% NPK + composted coir pith application. The increase in the soil phosphatase activity with the addition of organics could be attributed to the soil substrate enrichment by addition of mineral fertilizer. The phosphates added through organics and fertilizer improved the phosphatase activity which may be ascribed to the stabilized extra cellular fraction of enzyme (Nannipieri, 1994).

Reddy and Reddy (2009) found that graded doses of organic N with graded doses of inorganic N increased the phosphatase activity of the soil. Singaram and Kamalakumari, (1995) reported that continuous application of N, P and K fertilizer with FYM resulted in the increased activity of enzymes \textit{viz.} amylase, catalase, dehydrogenase, phosphatase and urease. Stimulation effect of organic sources alone or in integration with inorganics was significantly higher than the chemical fertilizer alone. In case of acid phosphatase activity, it was also found that organic manure with inorganic fertilizers had the highest stimulation of enzyme activity

Prasanna (2004) in a study relating to recycling of paddy straw in an acid lateritic soil of Bhubaneswar through bio-inoculation found that both urea and bio-inoculants influenced the enzyme activity from 3\(^{rd}\) week onwards. Straw incorporation maintained higher activity in the 1\(^{st}\) two weeks than straw burning. Results on urease and phosphatase activity showed that the treatments significantly influenced the urease activity, but not the phosphatase activity.
Acid phosphatase secretion is increased from plant roots when there is signal indicating P deficiency in the soils to enhance the solubilisation and remobilisation of phosphate, thus influencing the ability of the plant to cope with P stressed condition (Muchhal et al., 1996; Daram et al., 1999; Kartikeyan et al., 2002; Mudge et al., 2002; Hayes et al., 1997 and Li et al., 1997).

Majhi et al., (2016) found that phosphatase activity was also significantly enhanced by NPK fertilizer application. In all fertilizer treatments the activity varied within a relatively narrow range between 279 and 394 mg p- nitrophenol kg$^{-1}$ soil hr$^{-1}$ with a coefficient of variation of 1.93 to 3.49% only. Highest phosphatase activity was measured in 100% NPK + FYM treatment that continuously received 10t FYM per year. Increasing the NPK dose to 150% also increased the phosphatase activity. Application of Zn, B and S had positive impact on soil phosphatase activity. But in each case the enhancement was not significant. Combined application of Zn and S along with 100%NPK however, caused significant increase the phosphatase activity. Phosphatase activity strongly correlated with urease activity (r =0.93**) and SOC (r= 0.98**).

Srilatha et al., (2013) experimenting on a rice-rice system reported an increase in enzyme phosphatase activity up to active growth stages of crop and later showed decrease. The activity of acid and alkaline phosphatase was highest with application of 150% NPK followed by 100% NPK +FYM @ 10 t ha$^{-1}$. Phosphatase activity was at its peak at 60 days after transplanting stage.

2.1.3.1.3 Urease Activity

Majhi et al., (2016) working on a long term experiment with rice-rice system reported that urease activity measured on soils of post harvest summer crop varied widely from a lowest of 30mg to a highest of 79.12 mg NH$_4^+$-N kg$^{-1}$ soil 24hr$^{-1}$ found in 100%NPK+ FYM treatment with co-efficient of variation
of 7.48 to 16.50% which was much higher than that of phosphatase and dehydrogenase and it also strongly correlated with SOC ($r=0.94^{**}$).

Application of 100% NPK caused significant increase (78.1% more) in urease enzyme activity over control. Increasing the NPK dose to 150% also resulted in further increase in urease activity. Application of Zn or B or Zn + B over 100% NPK did not have any significant effect. Application of boron over and above 100% NPK + Zn decreased the urease activity although it was not significant. Negative impact of zinc + boron on soil urease might be due to addition of lesser biomass (Balu Ram et al., 2014; Singh, 2012) that did not have any significant effect on SOC which had strong correlation with urease ($r=0.94^{**}$). Application of S had no impact on enzyme urease even after 9 cropping years. Application of FYM caused much higher increase (115%) in urease activity. Sardans et al., (2008) observed the seasonal changes in soil urease activity and found higher urease activity in winter when the soil temperatures were lower than summer.

Elayeraja and Singravel, (2011) found that application of inorganic fertilizers and various organic sources had profound influence on urease activity. Application of 150% NPK registered the highest urease activity. Among the organics, application of composted coir pith @ 12.5 t ha$^{-1}$ recorded the highest urease activity of soil followed by press-mud application. The increased rate of N application and various biomaterials added to the soil as well as root exudates promoted the production of nitrogenous substance which induced the urease activity. The results were in agreement with the results obtained by Rao and Pathak (1996). In an earlier study, Lui et al., (1990) showed that use of organic matter in addition to chemical fertilizers increased soil organic matter and total N which increased the population of soil organisms and activities of enzymes such as urease.

Roy et al., (2011) reported that application of fertilizer N in crop residue amended soils caused sharp increase in urease activity under rice-wheat cropping sequence. Incorporation of crop residues in presence of rice crop increased urease activity up to 14 day after urea application. 50% replacement
of dose of N by organic manure increased the activity of urease and phosphatase by 33-46% and 35-74% respectively. It showed significant improvement in soil fertility and biological properties (Guan et al., 2011).

Stakurlova and Shchorbakov, (1996) reported that there was inhibition of soil potential N fixation due to high concentration of NO\textsubscript{3}\textsuperscript{-}, but the effect was temporary. It was reported that high concentration of NO\textsubscript{3}\textsuperscript{-} caused a decrease in protease and urease activity. Elayaraja and Singravel, (2011) reported that application of inorganic fertilizer and various organic sources had profound influence on the urease activity. The increased rate of nitrogen application and various biomaterials added to the soil as well as root exudates promoted the production of nitrogenous substances which induced the urease activity.

Bandick and Dick, (1999) reported that elevated soil concentration of chemical compounds that are end products of enzymatic reactions can inhibit enzyme activity by feedback inhibition. Urease activity may be suppressed by NH\textsubscript{4}\textsuperscript{+} based N-fertilizer because NH\textsubscript{4}\textsuperscript{+} is the end product of urease activity. Similarly phosphatase activity increases in phosphorous deficient soils, but decreases in soils with high phosphorous concentration. pH is negatively correlated with urease activity (Wu Ji You et al., 2010).

Patnaik et al., (1999) reported that surface soil had the highest urease activity followed by sub-surface soil and flooded soil. Urease bound to the surface of rice roots and exo-cellular urease may hydrolyse organic substances in the soil.

Mohapatra et al., (1977) showed that the urease activity is significantly correlated with total N (r =0.91**) and organic carbon (R=0.89**), but not the CEC, clay or pH. Multiple regressions showed that organic matter content of soil measured by organic carbon and total N accounted for most of the variation in urease activity.

2.1.3.2 Soil Microorganisms

Microbes are one of the sources of soil enzyme. Inorganic fertilizer influences microbial activity. Work done at CRRI, Cuttack revealed that application of N and P fertilizers to rice soils increased the number of
actinomycetes and bacteria, but K had no significant effect. The total number of fungi was however not affected by the application of fertilizers (Rangaswamy and Venkateshan, 1996).

Soil pH is one of the most important factors influencing residue decomposition as it affects both the nature and size of the population of microorganisms and the multiplicity of enzymes at the microbial level which subsequently affect decomposition of crop residues (Paul and Clark, 1989). In general, the decomposition of crop residues proceeds more rapidly in neutral than in acid soils.

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The effects of organic amendments, such as FYM on soil micro faunal populations depend largely upon the effects of the amendment on soil fertility and plant growth. The total number of protozoa and the number of active amoebae and ciliates was significantly higher in soil treated with FYM or complete mineral fertilizer than in untreated soil. Similarly, increases in protozoan abundance in soil treated with inorganic fertilizers (e.g. nitrogenous fertilizers) have been reported (Viswanath and Pillai, 1977; Elliot and Coleman, 1977; Griffiths, 1990).

In a study, Gupta and Germida (1988) reported that application of elemental S fertilizer to soil for five years resulted in a 30-71% decline in population of bacteria feeding protozoa and > 84% decline in populations of micophagous amoebae. The effect of fertilizer application on nematode populations are varied and changes in both the abundance and tropic diversity of nematodes in response to fertilizers have been reported. Sohlenius and
Bostrom (1986) and Sohlenius (1990) reported that N fertilization (120 kg N ha\textsuperscript{-1}) resulted in a large increase in nematode abundance compared to no N fertilization. The positive effect of N fertilization was attributed to an increase in plant production, root biomass and microbial activities in the soil. Wasilewska, (1989) and Bongers \textit{et al.}, (1991) observed a reduction in nematode numbers following the application of fertilizers N. Rodriguez-Kabana (1986) reported that organic (oil cake) and inorganic amendments (300 kg N ha\textsuperscript{-1} as anhydrous ammonia and 130 kg N ha\textsuperscript{-1} as urea) were effective nematode suppressants.

Application of both organic and inorganic fertilizers may cause significant changes in nematode tropic diversity. Generally applications of fertilizers increase the proportion of root feeders (Yeates, 1987) and bacterial feeders (Yeates, 1982; Sohlenium and Wasiliewska, 1984; Bohlen and Edwards, 1994) and decrease the proportion of fungal feeders and omnivores (Sohlenius and Wasiliewska, 1984) in both agriculture and forestry systems.

Kukreja \textit{et al.}, (1991) revealed that total microbial biomass significantly increased in plots receiving 90t ha\textsuperscript{-1} FYM annually for twenty years. They further found that the basal respiration level of population at higher levels of carbon was less than that of the population at lower levels of carbon in soil during the period when soil respiratory activity had stabilized.

\textbf{2.1.3.2.1 Microbial Biomass Carbon (MBC)}

Microbial biomass is defined as the living component of soil organic matter but excludes macro fauna and plant roots (Jenkinson and Ladd, 1981). As a very broad generalization, the amount of microbial biomass in a soil reflects the total organic matter content, with the living microbial component forming a low proportion. The proportion present as living microbial cells (microbial biomass Cg\textsuperscript{\text{-1}}soil) typically comprises 1-5% (w/w) of total soil organic C and microbial N forms 1-6% (w/w) of total organic N (Jenkinson and
Ladd, 1981; Wardle and Barker, 1992). Bhattacharya et al. (2001) reported that compost addition increased the microbial biomass carbon and soil respiration.

Microbial biomass has been found to be a sensitive indicator of management induced changes in soil biological properties (Carter, 1996 and Powlson et al., 1987). Changes in biomass are induced by tillage practice, incorporation of crop residues, N fertilization, crop rotation and changing soil-moisture regimes (Carter, 1996 and Powlson et al., 1987; Gupta and Germida (1988) found that microbial biomass C was lower in cultivated soil than undisturbed soil. However, although it is generally assumed that microbial biomass and activity measurements are correlated with soil organic C because soil biomass depends on the quantity of degradable C sources present in the soil, this relationship is not always found (Insam et al., 1989). Shifts in biomass C measured over relatively short time periods do give an early indication of change in soil organic matter levels long before they could be detected by other methods (Powlson et al., 1987). For this reasons, measurement of microbial biomass C in the top-soil has the potential to be used as a sensitive indicator of change in soil biological properties due to soil and crop management differences. The microbial biomass C in the top 0.20m of the soil was significantly (P<0.01) increased by the application of manure but not by the application of NH$_4$NO$_3$ (Rochette and Gregorich, 1998).

The microbial biomass component of soil organic matter has the potential to be a sensitive indicator of organic matter dynamics because the microbial fraction changes comparatively rapidly and differences are detectable before they can be measured in total organic matter (Powlson and Jenkinson, 1981; Powlson et al., 1987).

Sparling (1992) found that microbial biomass C and the soil organic C ratio were useful to measure soil organic matter dynamics and provided a more sensitive index than whole Soil organic C measured alone. Rochette and Gregorich (1998) showed that the ratio of microbial biomass carbon to total organic carbon was about 1.5% in control and fertilized treatments and 3.5% in manure treatments. Soil microbial biomass represents only a small proportion of overall SOM, it is more dynamic than total SOM and a better indicator of
how tillage and cropping systems impact soil health and productive capacity (Campbell et al., 1991).

Srinivas et al., (2015) in a long term experiment on rice-rice cropping system found that FYM and mineral fertilizers (NPK) caused significant build-up of the microbial biomass carbon and soil enzyme activities.

A good example of microbial biomass differences associated with soil management is a study involving two field experiments in Denmark in which spring barley straw had been burned or incorporated in the soil for 18 years (Powlson et al., 1987). Straw incorporation increased total soil organic C by only 5%, and total soil N by about 10%. However, microbial biomass C increased by about 45%, an easily measurable change. Management of soils that leaves residue on the soil surface often results in higher concentrations of soluble organic carbon compounds (Alvarez et al., 1995), which may result in the enhancement of microbial properties.

According to Bucher (1999), soil microbial biomass C (SMBC) increased with manure addition as compared to industrial fertilizer addition on Pennsylvania farms that had different soil management histories. In addition, the SMBC for continuous corn was significantly greater with manure additions (325 g C g⁻¹ soil) than with industrial fertilizer (156 g C g⁻¹ soil) in a long-term rotation experiment with different crop sequence and nutrient source treatments. Hasebe et al., (1985) and Ritz et al., (1997) also observed greater microbial biomass C in soil treated with organic manure than with inorganic fertilizers or no-fertilizer treatment. Finally, Bucher (1999) measured greater SMBC as small grain and forage crops were added to rotations as compared to continuous corn with either fertilizer or manure treatments. According to Mausbach and Seybold (1998), the range of microbial biomass C is 75-700 g C g⁻¹ soil. This range is based on literature findings and is not soil specific nor for a specific land use.

Gupta and Germida (1988) found that microbial biomass C, N and S were all lower in cultivated soil as opposed to undisturbed soil. However, although it is generally assumed that microbial biomass and activity measurements are correlated with soil organic carbon because soil biomass
depends on the quantity of degradable C sources present in the soil, this relationship is not always found (Insam et al., 1989).

Anderson and Domsch (1989) compared the ratio of MBC/SOC between permanent monoculture plots and continuous crop rotation plots and suggested that a higher concentration of MBC is the characteristic of crop rotations. On an average proportion of total organic C as MBC was 2.3% for permanent monocultures and 2.9% for the continuous crop rotations. In another study Rochette and Gregorich, (1998) showed that the ratio of MBC to total organic C was about 1.5% in control and fertilized treatment and 3.5% in manures treatments.

Santhy et al., (2002) in a long term experiment on rice found that soil biomass carbon was higher in 100 per cent NPK + FYM treated plots than 150 per cent NPK alone. There was a gradual increase in biomass C content of soil for the graded levels of NPK from 50 to 150 per cent and application of 100 per cent NPK along with FYM recorded highest biomass C (Selvi et al.,2004).

Bhattacharyya et al., (2008) showed a marked increase in soil microbial biomass and enzyme activity when farmyard manure was added. Long-term application of high rate compost can increase microbial biomass carbon in the soil by up to 100%, and sludge application can increase enzymatic activity by 30% (Diacono and Montemurro, 2010).

Senapati, et al., (2011) reported that the growing rice crop without any nutrient leads to lower carbon content which indirectly affects the microbial population. On the other hand as the higher dose of inorganic fertilizer as well as secondary nutrient (100% NPK + Zn + B + S) caused significant increase in microbial population over control plot. Application of 15 ppm Zn decreased microbial activity in the rhizosphere (Dey and Chattopadhyay, 1978).

Rochette and Gregorich (1998) revealed that manure amendments increased the microbial carbon by 2 to 3 folds compared to control. Yan et al. (1998) and Dinesh et al., (2000) found that soil microbial biomass carbon increased greatly with the application of organic manures. Similar results were
also reported by Kumari et al., (2011). Microbial biomass carbon increased with increase in doses of inorganic fertilizers. It may be firstly due to increase in microbial population and secondly due to the formation of root exudates, mucigel soughed off cells and underground roots of previous cut crops, which also play an important role in increasing biomass C (Goal et al., 1992).

In a study conducted on a long term experiment at RRTTS at Keonjhar, Orissa with a rice-pulse cropping system on a mixed red and black soil, Rout et al., (2003) reported that after 12 years cropping system 5t FYM ha$^{-1}$ as supplement to NPK maintained higher levels of both SOC and MBC than NPK alone indicating significant influence of FYM. This is in agreement with Goyal, (1993) who showed addition of organic amendments increased MBC resulting from greater rhizo deposition. From a long-term fertilizer experiment on rice–rice cropping in typic Endoaquept, at the CRRI, Cuttack it was reported that compost application, even once a year, invariably led to higher increments in both soil carbon and microbial pools.

2.1.3.2.2 Soil Respiration

In a study Senapati et al., (2011) found that carbon dioxide evolution was an important indicator for measuring the microbial activity and rate of decomposition of organic matter.

Bhatia et al., (2013) reported that the effect of continuous use of inorganic fertilizers and organic manure for 38 years on yield of rice (Oryza sativa) and soil biological properties was studied for two consecutive years during 2009 and 2010 in rotation of wheat at Pantha Nagar. The experimental soil was an aquichapludoll with silty clay loam texture. The treatment of 100% NPK + 15 t FYM ha$^{-1}$ also recorded maximum and significantly more mean soil microbial biomass C of 24.1%, soil microbial biomass N of 53.2%, soil dehydrogenase activity of 18.2%, urease activity of 33.9% and respiration rate of 40.5% than 100% NPK alone. The treatments of 100% NPK, 100% NPK+
Zn and 100% NPK+ Hand weeding were at par and superior to the control in different soil biological properties.

Bilen et al., (2011) reported the effects of different levels of boron fertilizer on microbial population, microbial respiration and soil enzyme activities in different soil depths in cultivated wheat soils. The highest population of bacteria, fungi, actinomycetes and CO$_2$-C production were observed at 3 kg ha$^{-1}$ B level in different growing periods of the plant and in different soil depths. Urease, phosphatase and dehydrogenase enzyme activities showed a significant (p< 0.01) positive correlation with B applications. The highest urease activity was observed in 6 kg ha$^{-1}$ B level and the highest phosphatase and dehydrogenase enzyme activities were observed with 3 kg ha$^{-1}$ B level at harvest period in both the soil depths.

2.2 Effect on Grain Yield

2.2.1 Effect of NPK fertilizers and FYM

Shri Ram et al., (2016) over 41 years of study in a silty clay loam hyperthermic aquic Hapludoll of rice-wheat cropping system, found that 100% nitrogen, phosphorus, and potassium (NPK) + farm yard manure (FYM) at 15 t ha$^{-1}$ recorded the most sustainable grain yields. Super optimal NPK (150%) fertilizers gave quite similar crop yields to that of 100% NPK + FYM at 15 t ha$^{-1}$ up to two decades but thereafter yields declined sharply due to emergence of zinc (Zn) deficiency. Continuous cropping over a period of 41 cropping cycles without fertilizers (control) reduced the grain yields of rice considerably from 27.8–60.5% to that of wheat (1.9–35.3%) with respect to initial yields. In contrast in a study conducted on typic Ustochreptson a clayey soil of Andhra Pradesh Srilatha et al., 2014 however, reported more yield with 150%NPK than 100%NPK +FYM. Higher yield in 150% NPK without FYM is due to
accumulation of more organic matter through more roots and stubbles (Swarup, 2000, Srilatha et al., 2014).

In a study, Biswas and Bhattacharya (1987) observed that increasing nitrogen rates from 0 to 100 kg ha$^{-1}$ increased the rice yield from 3.5 to 5.0 t ha$^{-1}$ in wet season and from 2.7 to 3.7 t ha$^{-1}$ in dry season. Further increase in nitrogen up to 150 kg ha$^{-1}$ did not produce significant variation in yield. Similar results were also reported by Islam et al., (1990).

Mitra et al., (2001) conducted an experiment in the alluvial soils (Inceptisol) of Orissa, India, at two locations (Village Siula in Puri district and Village Uttara in Khurda district) for three consecutive years in a rice-groundnut sequence with four levels of K$_2$O (0, 30, 60, 90) for rice and three levels of K$_2$O (72, 60, 80 kg ha$^{-1}$) for groundnut. The results showed a significant increase in yield of both rice and groundnut with increased levels of K. Averaged over cropping cycles, application of 60 kg K$_2$O was found to be optimum for kharif rice.

Sahu and Nanda (1997) carried out two field experiments, one in black soil and another in laterite soil to determine the response of rice cv. Jajati and Lalat to sulphur (0-60 kg/ha) in Orissa. They observed that the grain yield increased up to 40 kg S (5.06 t ha$^{-1}$) although highest yield was obtained with 60 kg S (6.24 t ha$^{-1}$) on the laterite soil. Bhuiyan and Islam (1989) conducted a long term field trial with 3 rice crops (BoroAus and T. aman) silt loam soil and observed that the grain yield of rice increased markedly with the application of S as gypsum. They further reported that the application of S with NPK + Zn compared with NPK + Zn alone significantly increased yields of rice.

Bornali Mostofa et al., (2015) reported that the soil productivity and health were more sustainable with the integrated application of manure and inorganic fertilizers than that of only use of inorganic fertilizers. The treatment with the recommended dose of N, P, K, S and Zn gave the best yield in both boro and aman season.
Thakur et al., (2011) also reported that integrated use of optimal dose of fertilizer and organic manure treatments is superior to super optimal dose. But sustainability with recommended dose of fertilizer and conjunctive use of secondary and micronutrients was found to be poor. The results clearly suggested that application of inorganic fertilizers at the conventional recommended dose with Zn + B or Zn + S is not enough to sustain crop yield.

Reddy et al., (1986) conducted field experiments for two kharif and rabi seasons to study the direct and residual effect of micronutrients on rice in typic Ustochrept, black clay soil. They reported that the residual effect of micronutrients on rabi rice was higher compared with direct application to kharif rice. Application of zinc, manganese and molybdenum along with NPK favorably influenced yield attributes and rice grain yields. Application of zinc alone resulted in higher grain yield both by direct application to kharif rice and as residual effect to rabi crop. In contrast, higher grain yield of rice and wheat was observed with cumulative application, as compared to direct and residual application of Zn in rice- wheat cropping system (Hussain, 2006; Ingle et al., 1997). Rathore et al., (1982) reported Zn  22 kg ha\(^{-1}\) increased grain and straw yields by 21.8 to 28.7% and 8.6 to  50.55% respectively. They further observed that the grain yield was positively correlated with plant zinc content. The critical Zn concentration for response to zinc fertilizer was 13.5 ppm in rice plant.

Zaman et al., (1994) in a field trial on non-calcareous dark grey floodplain soils reported that application of Zn had a positive effect on grain yield, 1000-grain weight, Zn and Mn contents and negative effect on K, S, and Fe contents in rice grain (BR11). The combined effect of P and Zn influenced P, Zn, S, K and Mn contents but failed to show significant effect on Ca and Mg up take Positive response to Zn has also been reported by many workers (Ali et al., (2013) and Khurana et al., (2002), Pal and Jena (2012); Dwivedi and Srivastva
Yield increase in rice from 5-19% in alluvial soils of Odisha has been recorded with Zn application @2.5kg ha\(^{-1}\) (Sahu et al., 1990).

### 2.2.2 Interaction of Nutrients

Shah (1993) conducted a field trial on course textured S and Zn deficient soil to study the interaction of S and Zn in relation to the nutrition and yield of rice. He found that S application at the rate of 50 kg ha\(^{-1}\) significantly increased grain yield over control, but Zn application had no effect on grain yield of rice. Zinc content in straw and Zn uptake at harvest decreased with increasing S levels but Zn level did not influence S content and uptake. Khanda and Dixit (1996) in a field experiment conducted at Bhubaneswar, Orissa during summer 1991 and 1992 with 2 sources of Zinc (ZnSO\(_4\) and Zn EDTA) reported that application of Zn significantly increased the grain and straw yields over no Zinc application.

In another experiment, Saha and Datta (1991) concluded that application of Zn at 10 kg Zn ha\(^{-1}\) was sufficient to correct Zn deficiency in rice and significant response to S was obtained when 4 kg Zn ha\(^{-1}\) was applied together with 25kg S ha\(^{-1}\). Zn and S uptake correlated positively and significantly with grain yield. Zn content of rice plants increased when Zn was applied, the increase being most pronounced with 4 kg Zn ha\(^{-1}\). Zinc content however, decreased slightly when high doses of Zn were applied. Singh et al., (1983) working on an alluvial calcareous sandy loam soil reported that soil application of Zn up to 5 kg ha\(^{-1}\) significantly increased the grain and straw production while at 10 kg Zn ha\(^{-1}\) the yield decreased.

Boron takes part in the mechanisms of the nutrient absorption and transport of other nutrient elements (Tariq and Mott, 2007; Tanada, 1983). Depending on boron content in plants, the relative concentration of other elements and their balance in plants varies which affect dry mater production (Tariq and Mott, 2007). In a study Tyksinski, (1993) reported reduced yield in Zn + B treatment due to antagonism between zinc and boron. Mishra and Singh (1996) reported that high B supplies caused low uptake of Zn. Reduction in
grain yield at higher levels of S has been reported by Shah and De Datta, (1991). Both synergism and antagonism between Zn and S in the uptake and transport processes has also been reported by Pavansarivam and Axley, 1982). In contrast, Balu Ram et al. (2014) reported improvement of yield in hybrid rice under Varanasi situation with conjunctive use of S, Zn and B along with recommended dose of NPK.

Mousavi, et al., (2012) reported that high levels of phosphorus may decrease the availability of zinc or the onset of zinc deficiency associated with phosphorus fertilisation which is due to physiological factors. They also reported that sufficient amount of zinc in the plant improved the harmful effects of boron (B) deficiency. Zinc deficiency decreased plant growth by increasing the concentration of boron in the young leaves and tips of the branches. In contrast Rengel et al., (1998) observed that application of zinc increased boron uptake by plants in the soils with sufficient stores. Abdou et al., 2011 reported that the zinc deficiency may be related to weather conditions, zinc deficiency increases in cold and wet weather conditions. It may be due to the limited root growth in cool soils, or reduction activity of microorganisms and reduced release of zinc from organic materials. Mousavi, et al., (2012) also reported that zinc deficiency lead to iron (Fe) deficiency, due to prevention of transfer of Fe from root to shoot under zinc deficient conditions.

Raza et al., (2014) conducted a field experiment at Lahore to evaluate the effect of foliar application of boron (B) on yield and yield components of wheat in a calcareous soil. The results showed that effect of B was significant on grain yield, number of grains and 1000 grain weight. The highest grain yield of wheat (6.5 ton h\(^{-1}\)) was observed when 10 mg L\(^{-1}\) B was applied. Application of 20 mg L\(^{-1}\) B resulted in a significant decline in wheat grain yield (4.7 ton h\(^{-1}\)). The decline in the quantity and quality yields of with increasing boron might be due to the toxicity effect of higher concentration of foliar application.
2.3 Effect on Yield Sustainability

Katkar (2012) experimenting on sorghum-wheat cropping system in Vertisol of Akola, India reported that yield sustainability 100% NPK + FYM (0.432) was similar to that of 150% NPK (0.436). Application of only farmyard manure recorded relatively lower SYI (0.055) as compared to use of inorganic alone or in combination with FYM, Lowest SYI (0.006) was noticed in control treatment. This further justifies that, FYM alone or non-application of fertilizers could not sustain the yields of sorghum and wheat in long run. Although 150% RDF recorded higher SYI the need based use of micronutrients and sulphur would be more appropriate in the context of balanced nutrition. However, use of either organic manure @ 10 t ha⁻¹, under nutrition at 50-75 % of the recommended NPK or imbalanced supply of N alone or NP or NPK (-S or -Zn) led to un sustainability and a gradual reduction in productivity over period of cropping. This may be ascribed to the decline in soil fertility leading to nutritional deficiencies in crop plant.

2.4 Soil Quality and its Importance

2.4.1 Soil Quality

There are different definitions of soil quality each reflecting a different perspective on the use and value of soils: the potential utility of soils in landscapes resulting from the natural combination of soil chemical, physical, and biological attributes (Johnson et al., 1992); the capability of soil to produce safe and nutritious crops in a sustained manner over the long-term and to enhance human and animal health, without impairing the natural resource base or harming the environment (Parr et al., 1992); the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health (Doran and Parkin, 1994); the capacity of soil to function (Karlen et al., 1997) and how well soil does what we want it to do (Schjonning et al., 2003).

2.4.2 Importance of soil quality assessment

As health of a nation’s soil directly affects national security, sustaining soil quality is the most effective method for ensuring sufficient food to support
life. So it’s suggested that the responsibility of all people within a nation is to safeguard the integrity of the soil resource. Soil quality or soil health appraisal is needed to identify problem production areas, make realistic estimates of food production, monitor changes in sustainability and environmental quality as related to agricultural management.

In early 90’s Soil quality test kits (Liebig et al., 1996) and farmer based score cards (Romig et al., 1996) focusing on soil quality were developed. Later in the late 90’s various soil quality indexing approaches (Karlen and Stott, 1994, Andrews, 1998, 1999; Hussain et. al., 1999 Karlen et al., 1999b, Wander and Bollero 1999, Dalal and Moloney, 2000, Andrews and Caroll,2000; Andrews et al., 2002) were pursued. Soil quality can be assessed in two ways:

1. Qualitatively
2. Quantitatively

2.4.3 Qualitative Assessment

Various qualitative approaches (soil health score card, soil test kit) have been suggested by a number of scientists to measure soil quality. Qualitative measures of soil quality tends to be more subjective in their measurement, but can be assessed more easily, and sometimes be more informative to the land manager. In this approach for assessing scientists and agricultural professionals work with land managers to identify and describe soil quality indicators in their own terms. The indicators they choose can be easily observed and rated qualitatively.

2.4.4 Soil Health Score Card

Based on the farmer’s perception of soil quality; a scorecard was developed for assessing soil quality (Harris and Bezdick, 1994; Roming et al., 1995). The scorecard is a farmer- based subjective rating system that places indicators into three rating scales of healthy (score of 3.0-4.0), impaired (score of 1.5-2.0) and unhealthy (score of 0-1).
The Wisconsin soil health scorecard is a field tool to monitor and improve soil health based on field experience and a working knowledge of a farmer. It has 43 soil health indicator properties that integrate observations made throughout the growing season. The indicators are almost exclusively based on sensory observations (e.g. look, feel and smell). Correctly, the scorecard doesn’t recognize the relative importance of indicators, and is only developed cropping systems in Wisconsin. Modifications of the scorecard to encompass other regions and cropping systems would require structured input from additional farmers (Roming et al., 1997). For indicators either in the impaired and unhealthy categories, careful consideration is necessary to identify that caused the property to be in a less than optimum condition. Impaired indicator properties should be closely monitored over time to determine whether they are determining on improving. Unhealthy properties need immediate attention and corrective action.

2.5 Attributes of Soil Quality

Soils have chemical, biological and physical properties that interact in a complex way to give a soil its quality or capacity to function. Thus soil quality cannot be measured directly, but must be inferred from measuring changes in its attributes, referred to as indicators. Indicators of soil quality should give some measure of the capacity of the soil to function with respect to plant and biological productivity, environmental quality and human and animal health.

Doran and Parkin (1994) have defined as a set of specific criteria that indicators of soil quality must possess: they should (1) encompass ecosystem process and relate to process oriented modeling, (2) Integrate soil physical, chemical and biological properties and process, (3) be accessible to many users and applicable to field conditions, (4) be sensitive to variations in management and climate, and (5) where possible, be components of existing soil data bases. Also indicators should be easily measured and measurements should be reproducible (Gregorich et al., 1994).
Arshad and Coen (1992) also suggested that indicators should be sensitive enough to detect changes in soil as a result of anthropogenic degradation. The type of indicators used for assessing soil quality can vary from location to location depending on the kind of land or land use, soil function and soil forming factors (Arshad and Coen, 1992) and climatic conditions.

2.5.1 Physical Attributes of Soil Quality

Many soil physical properties act only indirectly on crop growth. Soil bulk density, for example, is often poorly related to plant yield, but does influence several other soil properties (e.g., strength, permeability, water retention) that can individually or collectively impact directly on crop productivity (Koolen, 1987; Carter, 1996). This characteristics common to many important soil properties, should be considered in the quest to identify potential soil quality attributes.

Bulk density, soil texture and penetration resistance are easy to understand and can thus provide useful indices of the state of compactness, translocation of water and air and root transmission. Measurements of infiltration rate and hydraulic conductivity are also very useful data, but are often limited because of the wide natural variation that occurs in field soils, and the difficulty and expense of making enough measurements to obtain a reliable average value (Camerron et al., 1998).

2.5.2 Chemical Attributes of Soil Quality

Dominant chemical indicators include soil pH, EC, CEC, organic matter and available nutrients (Dalal and Moloney, 2000).

Soil pH as an indicator can provide trends in change in soil health in terms of soil acidification, soil salinization, exchangeable sodium (soil structural stability) (Rengaswamy and Olsson, 1991), limitation to root growth, increased incidence of root disease, biological activity and nutrient availability.

Chaudhury et al., (2005) also observed that dehydrogenase was a good indicator in their minimum dataset, contributing 19.9% of variability in soil
quality index, when assessing soil quality under long-term rice-based cropping system in Gangetic Inceptisol. CEC values ranged between low and medium in magnitude considering the values found in soils of tropical and subtropical countries. Basak (2011) established that a CEC value of 14.9 cmol(+) kg\(^{-1}\) was ‘optimum’ for Inceptisol for harvesting 80% yield potential of a rice-based cropping system.

Electrical conductivity can provide trends in salinity for both soil and water, limitations to crop growth and water infiltration and along with pH, it can be a surrogate measure of soil structural decline (Rangaswamy and Olsson, 1991). The cation exchange capacity as indicator monitors the capacity of the soil to retain cations and its capacity to adsorb pesticides and chemicals and thus it provides a filter against chemical contaminants (Karlen \textit{et al.}, 1997a). Soil organic matter (SOM) has been suggested as the single most important indicator of soil quality and productivity (Larson and Pierce, 1991; Doran and Parkin, 1994). It is one of the more useful indicators of soil quality, because it interacts with other numerous soil components; affecting water retention, aggregate formation, BD, pH, buffering capacity, cation exchange properties, mineralization, sorption of pesticides and other agrichemicals, colours, infiltration, aeration and activity of soil organisms (Schnitzer, 1991). Trends in available plant nutrients for example: N, P, S and K indicate the systems sustainable land use, especially if the nutrient concentration and availability are approaching but remain above the critical or thresh hold values. In the long term, nutrient balance of the system is essential to sustainability. Thus available nutrients are indicators of the capacity to support crop growth, potential crop yield, grain protein content (Dalal and Mayer, 1986) and conversely, excessive amounts may be a potential environmental hazard.

\subsection*{2.5.3 Biological Attributes of Soil Quality}

Soil is a heterogeneous mix of living and non living components including microbes, plant roots and soil invertebrates which have extremely important effect on soil characteristic relevant to soil quality.
2.5.3.1 Microbial Population

The soil is a habitat for a vast number of diverse organisms. Bacteria and fungi and the activities they perform are integral to the development and maintenance of a healthy soil. There are typically $10^4$ - $10^6$ fungal propagules per gram of soil compared to $10^6$ - $10^9$ bacteria per gram soil (Lynch, 1983). However, fungi may account for as much as 70% by weight of the soil biomass (Lynch, 1983).

Total population of bacteria and fungi in the soil are sensitive to and respond differently to soil management practices. The presence or absence of the organisms in the soil can be used as indicators of soil health and soil productivity as they are all capable of having a direct effect on plant growth.

Population densities of algal and protozoa in soil have been estimated to be $10^1$ - $10^6$ per gram of soil for algal and $10^4$-$10^5$ for protozoa (Atlas and Bartha, 1987). Population densities may vary widely with seasons and vegetation differences. Abundance of varies microbial taxa in soil regularly various with different agronomic management practices. In general bacterial and fungal population immediately proliferate upon organic amendments (Fraser et. al., 1998).

2.5.3.2 Microbial Biomass Carbon (MBC)

The soil microbial biomass is the living microbial component of the soil comprising mainly bacteria and fungi but also including soil micro-fauna and algae. Although microbial biomass accounts for only 1-3% of the organic C and 2-6% of the organic N in soil (Jenkinson, 1987) it plays a key role in soil organic matter dynamics. It controls the transformation of organic matter in soil and influences C storage and is both a sink (during immobilization) and temporary source (during mineralization) of plant nutrients.

Because of its high turnover rate relative to the total soil organic matter, the microbial biomass can quickly be reported to changes in soil process resulting from changes in management. The microbial biomass C can be
divided by total organic C (Anderson and Domsch, 1989) or CO₂–C respired (Visser and Parkinson, 1992) in order to make comparisons between soils under different managements having different organic matter contents. Changes in the ratios generally reflect both organic matter inputs and outputs from the soil and conversion of organic matter to microbial biomass C. Sparling (1997) suggested that because the ideal microbial biomass content for a healthy soil has not been defined it is crucial that a soil specific baseline be used for comparisons. The target value can be derived from the same soil type under alternative land management. Although useful as research tool, its cumbersome measurement and variability with short term environmental conditions makes it as routine soil health indicator currently difficult (Sparling, 1997; Dalal, 1998).

In contrast, a higher microbial biomass did not necessarily relate to greater soil fertility as assessed by the amounts of plant available P extracted from soil or plant yield (Sorn-Srivachai et al., 1988). More biomass carbon and nitrogen was found under wheat receiving N fertilizer (Biedarbeck et al., 1984). Tate et al., (1991) found more organic matter and a greater microbial biomass C on a low fertility pasture site compared to a high fertility site.

2.5.3.3 Microbial Biomass Nitrogen (MBN)

Campbell et al., (1991) reported that the microbial biomass nitrogen was more useful in predicting a change in soil quality than microbial biomass carbon. In contrast, Jordan and Kremer (1994) reported microbial biomass carbon to be a better indicator of soil quality. This conflict demonstrates the need for both measures and careful interpretation with other measures for accurate assessment of soil quality.
2.5.3.4 Microbial Quotient

Several authors have suggested that the microbial quotient (MBC/SOC) indicates changing soil processes and soil health and is a more useful measure than either MBC or SOC considered individually (Anderson and Domsch, 1989; Sparling, 1992). Soils under monocropping have lower quotients than those under multi cropping (Anderson and Domsch, 1989). The ratio of MBC to total organic C has been useful to elucidate changes in organic matter under different cropping (Anderson and Domsch, 1989) or tillage (Carter, 1999) systems, as well as in soil polluted by heavy metals (Brookes, 1994).

Sparling et al., (1992) found the approach useful to normalize data from a chronosequence of cropping sites; and to obtain a much clear indication of changing to organic carbon contents with time. The microbial quotient, are useful to determine trends with time and to compare soils, and but our current knowledge is such that there is no particular value that can be regarded as healthy.

2.5.3.5 Microbial Respiration

Microbial respiration refers to the metabolic activity of microorganisms. Microbial respiration is a well established parameter to monitor decomposition (Anderson 1982); but it is also highly variable and can fluctuate widely depending on substrate availability, moisture and temperature (Orchard and Cook, 1983; Alvarez et al., 1995 and Brookes, 1995). Soil organism can respond very rapidly to a change in soil conditions even after long periods of inactivity. The great variability is respiration means that this measure taken alone is very difficult to interpret in term of soil health (Brookes, 1995).

2.5.3.6 Respiratory Quotient

Respiratory quotients were used by Brookes and Mc. Grath (1994) to assess effects of application to soils of heavy metal contaminated sewage sludge. The respiratory quotients (qCO\textsubscript{2}) were substantially high in the sludge
amended in soils. In this case the higher respiratory quotients suggest a stress response and poor health. Under stress condition many soil organisms becomes dominant, the respiratory ratio (CO$_2$ production per unit of microbial biomass carbon, qCO$_2$) is indicative of general microbial biomass but a high production of microbial biomass C to soil organic C. The respiratory ratio, qCO$_2$also has high, possibly indicating that more C was being lost and that greater care was needed to maintain soil organic matter levels.

2.5.3.7 Enzyme Activity

Soil enzyme activity is often closely related to soil organic matter, microbial activity and microbial biomass. It is sensitive to change in management practices. Dehydrogenase is a potential indicator of active soil microbial biomass. However, it is very sensitive to seasonal variability. Potentially useful indicators of soil health could be beta-glucosidase, urease, amidase, phosphatase and aryl sulphatase and fluorescein diacetate hydrolyzing enzymes.

2.5.3.8 Soil Invertebrates

Although most biological measurement to date have focused on microbial population activity, there is growing awareness of the importance of the soil invertebrates as vital components of soils and as potential indicators of soil quality. Works on soil invertebrates ecology conform that soil invertebrates affect soil structure, microbial activity and influence SOM dynamics and nutrient cycling (Venhoef and Brussaard, 1990; De Ruiter et. al., 1994).

Both nematodes and earthworms respond to soil disturbances and significantly influence soil processes and therefore can serve as useful indicator species when assigning the effects of various land management practices or anthropogenic impacts on soil quality. The two groups of invertebrates participate in different levels of the soil food web, influence nutrient cycling and soil structural changes at varying scales and reflect different levels of disturbance in the soil physical and chemical environment. Many studies
indicate that the abundance and composition of free living soil nematodes are related to the status of the soil microbial community and processes (microbial biomass, fungal/bacterial ratios, N-mineralization rates). Nematodes also appear to respond quickly in predicative ways to disturbance in ecosystems (Wasilewska, 1989; Freckman and Ettema, 1992; Ettema and Bongers, 1993; Yeates and Bird, 1994). Response for the interest in nematodes as indicators have been outlined by Bongers (1990) and Linden et al., (1994). These include: (i) the tremendous diversity of soil nematodes and their participation in many ecosystem functions at different levels of the soil food web; (ii) the rapid response of nematodes to changes in their food resource base, because of their small size and short generation times.

Earthworms also have great potential as indicators of soil quality. Earthworm population densities can be related to SOM levels (Hendrix et al., 1986), soil physical disturbances such as tillage (Lee, 1985) and potentially harmful chemicals (Edwards and Bohlen, 1992, 1995a). The population density of earthworms tends to increase with soil disturbance. Through their feeding and burrowing activities, earthworms tend to increase with increasing organic matter inputs and decrease with soil disturbance. Through their feeding and burrowing activities, earthworms significantly alter soil structure and hydrologic properties (Tomlin et al., 1995) and make substantial contribution to nutrient mineralization (Didden et al., 1994). Earthworms also influence other important biological indicators of soil quality, particularly the soil microbial biomass (Blair et al., 1996).

2.6 Selection of Indicators of Soil Quality

It would be unrealistic to use all ecosystem or soil attributes as indicators, so a minimum data set (MDS) consisting of a core set of attributes encompassing chemical, physical and biological soil properties are selected for soil quality assessment (Larson and pierce, 1991). To assess soil quality, Larson and Pierce (1994) suggested measuring various soil attributes or
indicators that controlled or were influenced by various soil functions. There are different ways how indicators are selected. Broadly there are three ways by which scientists have selected the indicators. Those are:

1. Indicators as suggested by scientists
2. Indicator selection by simple scoring and elimination approach
3. Indicator selection through a statistical framework

2.6.1 Indicator sets as suggested by scientists

Several authors have proposed sets of soil quality indicators (Larsen and pierce, 1991; Doran and Perkin, 1994 and Karlen et al., 1998). A common feature of the indicator sets is that they all include some combination of physical, chemical and biological soil properties suggesting that for a soil to function effectively all three components must be addressed.

Doran and Parkin (1994) developed a list of basic soil properties or indicators for screening soil quality. They are: (1) Physical indicators: soil texture, depth of soils, top soil or rooting, infiltration, soil bulk density and water holding capacity. (2) Chemical indicators: soil organic matter or organic carbon and nitrogen, soil pH, electrical conductivity and extractable N, P and K (3) Biological indicators: microbial carbon and nitrogen, potential mineralizable N and soil respiration.

Harris and Bezdick (1994) indicated that soil quality indicators might be divided into two major groups; analytical and descriptive descriptions. Hussain et al., (1999) selected some indicators for the evaluation of Taiwan soils. The indicators were; (1) Physical: depth of the A –horizon, soil textural classes, bulk density, available water content and aggregate stability; (2) Chemical: soil pH, EC, organic carbon, extractable N, P, and K and extractable trace elements (3) Biological: potential mineralizable N, microbial C, N and P, soil respiration, the number of earthworms and crop yield. Because organic matter can have a tremendous effect on the capacity of a soil to function, it has been
recommended to be a basic component in every minimum data set for assessing soil quality (Gregorich et al., 1994).

### 2.6.2 Indicator selection by simple scoring and elimination approach

Cameron et al., (1998), suggested the use of simple scoring approach to help users decide whether to accept or reject a potential soil quality indicators for degraded or polluted soil. They used the equation, $A = f (S+U+M+I+R)$

Where, $A$ = Acceptance score for indicator  
$S$ = Sensitivity of indicators to degradation  
$U$ = Ease of understanding of indicators value  
$M$ = Ease or cost effectiveness of measurement of soil indicators  
$I$ = Predictable influence of properties on soil, plant and animal Health and productivity  
$R$ = Relationship to ecosystem process

Each parameter in the equation is given a score (1-5) based on the user’s knowledge and experience of it. The sum of individual scores gives the levels of acceptance ($A$) score which can be ranked in comparison to other potential indicators, thus aiding the selection of indicators for a site.

Dalal and Moloney (2000) suggested a scoring approach to select indicators by assigning scores (0 to 10) depending on the extent of fulfillment of these 10 criteria by any indicator. These criteria are: Indicator should

1. Respond to change in management practice and provide trends over time  
2. Be easily measured  
3. Have expected or threshold values  
4. Have low error associated with measurement  
5. Be stable in short term to enable measurement  
6. Not be required to be frequently measured  
7. Be cost effective
8. Have the ability to be aggregated from paddock or site to farm/catchment region

9. Be mappable in space and time

10. Have community acceptance and involvement

Finally for each indicator variable all the 10 score values are summed to get a total score and on the basis of the total score, indicators are either selected or deleted. Benchmarking the positive and undisturbed environments for soil quality and biodiversity using the sustainability indicators and then determining the extent of deviation from the bench values in a given landscape or environment may provide a suite of values. These values then could be integrated over space, attribute and time.

To develop soil quality index, Action and Gregorich (1995) stressed the importance of selecting appropriate indicators that influenced the capacity of a soil to perform various crop production or environment functions. It would be unrealistic to use all ecosystems or soil attributes as indicators, so a Minimum Data Set (MDS) consisting of a core set of attributes encompassing chemical, physical and biological soil properties are selected for soil quality assessment (Larson and Pierce, 1991).

Doran and Perkin (1994) developed a list of basic soil properties or indicators for screening soil quality. They are: (1) Physical Indicators: soil texture, depth of soils, topsoil or rooting, infiltration, soil bulk density and water holding capacity; (2) Chemical Indicators: soil organic matter or organic carbon and nitrogen, soil pH, EC, extractable N, P and K (3) Biological Indicators: microbial carbon and nitrogen, potential mineralizable N and soil respiration.
2.6.3 Indicator selection through a statistical framework

Some statistical techniques have been suggested for a minimum data set selection. Hatcher and Stefanski (1996) suggested for a two step analysis. Multivariate analysis of variance (MANOVA) was the first step used to determine whether there were significant inherent (regional) or management (tillage) effect on at least one of the physical, chemical and biological variables assessed. After this criteria was met, analysis of variance (ANOVA) of individual parameter was run on all the parameters. The obtained Wilk’s lambda and the F statistics derived from Wilk’s lambda were reviewed to test the null hypothesis of no overall treatment effect.

The second step considered was interpreting the univariate ANOVAs. Those variable for which the F-statistic was significant at P<0.06 (Hatcher and Stefanski, 1996) were retained for further analysis.

For comparing the alternate and conventional treatment means for 6 different farms, Andrews et al., (2002) used non parametric Wilcoxon rank sum ($C^2$) test on Jmpv-3 software for window (SAS institute, Carry, NC ). This nonparametric test finds differences less often than its parametric counterpart, the t-test (Ott, 1988). However, for farm they used one way analysis of variance (ANOVA) and students t comparison of means at $\alpha = 0.05$.

To select a representative MDS they first performed standardized PCA of all untransformed data that showed statistically significant differences between management systems using ANOVA or student’s t. They examined the PCs with eigen values $\geq$ 1 (Brejda et al., 2000b) and retained only the highest weighed variables from each PC of the MDS. Highest weighed variables remained within 10% of the highest factor loading (using absolute values). Under each PC they eliminated the redundant variables. Among well correlated variables within a PC, the variable with the highest sum of correlation coefficients (absolute values) were chosen for the MDS (Andrews and Carroll, 2001; Karlen et.al., 1999). If the highest weighted variables were
not correlated (assumed to be a correlation coefficient of < 0.60), then each was considered important and was retained in the MDS.

The principal components receiving high eigen values and variables with high factor loading were assumed to be variables that best represented system attributes. Therefore, only the PCs with eigen values ≥1 (Brejda et al., 2000) and those that explained at least 5% of the variation in the data (Wander and Bollero, 1999) were examined; three PCs had eigen values >1 that explained 86.8% of Variation in the data (Shahid et al., 2013). When more than one factor was retained under a single PC, multivariate correlation coefficients were employed to determine if the variables could be considered redundant and therefore eliminated from the MDS (Andrews et al., 2002a).

After eliminating the redundant variables through correlation tests, Andrews and Carroll, (2001) checked for possibility of further reduction in the number of variables in the MDS by performing a forward stepwise regression of the indicated variables against the higher order management goal variables. Following this technique they could eliminate the water stable aggregate variable from MDS. Finally they performed multiple regressions for MDS validation. They took litter disposal, yield (fescue biomass), P-runoff potential (resin P) and metal contamination (As) as goal functions for Alfisol site and Ultisol site. The $R^2$ values for the litter disposal at both sites were 0.81 and 0.85; for yield 0.56 and 0.35 for P-runoff potential, 0.86 and 0.91 and for metal contamination 0.74 and 0.75 respectively indicating these indicators (Zn, Cu, total N and pH at Alfisol site and available water, Ca, NO$_3$-N and pH at Ultisol site) to be representatives of the identified goal functions at both sites.

As check of how well the MDS represented the management system goals, Andrews et al, (2002) performed multiple regressions using the final MDS indicators as independent variables and management goals as dependent variables (Andrews and Carroll, 2001; Karlen, et al., 1999) such as yield (proportion of measuring yield/country average to account of different crops), gross revenues (including price minimums for organic produce) and SAR (to
represent sodicity concern in the region). Multiple regressions of the MDS indicators as independent variables and management goal data as iterative dependent variables yielded coefficients of determination ($R^2$) of 0.81 for proportional yield 0.84 for gross revenues and 0.77 for SAR. This suggested that the MDS is responsive to several management goals in this system.

The indicators used or selected by different researchers in different regions may not be the same because soil quality assessment is purpose- and site-specific (Wang and Gong 1998; Shukla et al., 2006). However, when selecting indicators, it is important to ensure that they: 1) correlate well with natural processes in the ecosystem, 2) integrate soil physical, chemical and biological properties and processes, and serve as basic inputs needed for estimation of soil properties or functions which are more difficult to measure directly, 3) be relatively easy to use under field conditions so that both specialists and producers can use them to assess soil quality, 4) be sensitive to variations in management and climate and 5) be components of existing soil databases wherever possible (Doran and Parkin 1996; Doran et al., 1996; Chen 1998).

The indicators which directly monitor soil quality are grouped into 4 categories as visual, chemical, physical and biological indicators (Dalal and Moloney 2000). Nortcliff (2002) stated that there are potentially many soil properties which might serve as indicators of soil quality and research is required to identify the most suitable. He also emphasized that the methods used in determining these indicators must be fully defined, otherwise the comparison of different sets of data may be of little value. Mairura et al., (2007) reported the integration of scientific and farmers’ evaluation of soil quality indicators and emphasized that the indicators for distinguishing productive and non-productive soils include crop yields and performance, soil colour and its texture. Parr et al., (1992) suggested that increased infiltration, aeration, macro-pores, aggregate distribution and their stability and soil organic matter, decreased bulk density, soil resistance, erosion and nutrient runoff are
some of the important indicators for improved soil quality. Further, Chaudhury
et al., (2005) identified total soil N, available P, dehydrogenase activity and
mean weight diameter (MWD) of aggregates as the key indicators for alluvial
biomass, respiration and ergosterol concentrations as very effective indicators
for assessing long-term soil and crop management effects on soil quality.
Assessment of soil-test properties from time to time has also been emphasized
for evaluating the chemical aspects of soil quality (Arshad and Coen 1992;
Karlen et al., 1992)

Sharma et al., (2005) reported a long-term experiment was conducted
using a strip split–split plot design on an Alfisol (Typic Haplustalf) in southern
India under sorghum-castor bean rotation. The key indicators, which
contributed considerably towards SQI, were available N, K, S, microbial
biomass carbon (MBC) and hydraulic conductivity (HC). On an average, the
order of relative contribution of these indicators towards SQI was: available N
(32%), MBC (31%), available (17%), HC (16%), and S (4%). Among the
various treatments, CTGLN90 not only had the highest SQI but also the most
promising from the viewpoint of sustainability, maintaining higher average
yield levels under sorghum–castor rotation. From the viewpoint of SYI, CT
approach remained superior to MT. To maintain the yield as well as soil quality
in Alfisols, primary tillage along with organic residue and nitrogen application
are needed.

Shahid et al., (2013) found that under PC3, DTPA-Zn was the only
highly weighted variable which has a significant role in lowland rice
cultivation and hence was retained. Multiple regressions between MDS and
management goals revealed that clay dispersion index (CDI) and available K
significantly influenced the management goals, while the effect of available N
was significant on Wet-SYI and System-SYI. Soil organic carbon had
significant influence on Dry-SYI and System-SYI, whereas DHA and DTPA-
Zn were significantly correlated with System-SYI. In summary CDI, SOC,
Avail-N, Avail-K, DHA and DTPA-Zn were retained for SQI estimation.
Of the various indicators, pH is one of the important indicators, which influence some of the soil functions. It can provide trends in change in soil health in terms of soil acidification (surface and subsurface) (Moody and Aitken, 1997), soil salinization, electrical conductivity, exchangeable sodium (soil structural stability) (Rengasamy and Olsson, 1991), limitations to root growth, increased incidence of root disease, biological activity, and nutrient availability (e.g. P availability at either high pH > 8.5 or low pH < 5; Zn availability at high pH > 8.5) (Doran and Parkin, 1996).

Electrical conductivity is a measure of salt concentration and therefore, its measure can provide trends in salinity for both soil and water, limitations to crop growth and water infiltration, and along with pH (indicating soil sodicity), it can be a surrogate measure of soil structural decline (e.g. high pH > 8.5 and low electrical conductivity < 0.1 dSm$^{-1}$) (Rengasamy and Olsson, 1991).

Organic matter is essential for good soil structure especially in low clay content soils, as it contributes towards both formation and stabilization of soil aggregates (Dalal and Mayer, 1986).

Trends in soil organic matter content provide an integrated measure of sustainable ecosystem (Karlen et al., 1997). Status of plant available nutrients, for example, N, P, K and S indicate the systems sustainable land use, especially, if the nutrient concentration and availability remain above the critical or threshold values. In the long-term, nutrient balance of the system is essential to sustainability. Thus, available nutrients are indicators of the capacity to support crop growth, potential crop yield, grain protein content (Dalal and Mayer, 1986), and conversely, excessive amounts may be a potential environmental hazard (e.g. algal biomass).

Biological soil quality indicators, soil microbial biomass and/or respiration, potentially mineralizable N, enzyme activity, fatty acid profile or microbial biodiversity, nematode communities and earthworm populations are quite predominant. Soil microbial biomass is a labile source and sink of
nutrients. It affects nutrient availability as well as nutrient cycling and is a good indicator of potential microbial activity (Dalal and Mayer, 1987). Respiration measurements are also similarly affected. However, respiration rates can be measured in the field using portable CO₂ analysers. Easily oxidizable N and potentially mineralizable N are measured by alkaline-KMnO₄ method and aerobic or anaerobic incubation respectively. Anaerobic method is considered to be more effective and is recommended as routine procedure. Potentially mineralizable N measures soil N supplying capacity and is also a surrogate measure of microbial biomass and a labile fraction of soil organic matter (Rice et al., 1996). Soil enzyme activity is often closely related to soil organic matter, microbial activity and microbial biomass. It is sensitive to change in management practice and can readily be measured. Of numerous soil enzymes, dehydrogenase is a potential indicator of active soil microbial biomass. However, it is very sensitive to seasonal variability. Potentially useful indicators of soil quality could be urease, phosphatase, and aryl-sulphatase and fluorescein diacetate hydrolyzing enzymes.

Basak et al., (2016) determined minimum dataset for assessing quality of soils belonging to three Soil Orders (Inceptisols, Entisols and Alfisols) by using statistical and mathematical models and 27 physical, chemical and biological attributes. Surface soils were collected from farmers’ fields under long-term cultivation of rice–potato–sesame cropping systems. For this purpose, separate PCA was performed for each of the Soil Orders with 27 soil attributes analysed. Each PCA analysis generated seven PCs. According to the criteria proposed by Kaiser (1960), the first six PCs were kept selected because they had eigen values >1.00 (Norman and Streiner 2008) and explained >5% of the variance in total dataset. PC₁ explained 37%, 37% and 34% of the total variance for Inceptisols, Entisols and Alfisols, respectively. Under PC₁ for Inceptisols, CEC was the highest weighted variable with component loading weight of 0.92. The chemical attributes pHₓ and available Zn were screened from PC₂ and PC₃, respectively. In PC₄, dehydrogenase showed highest
component loading, explaining 7.8% of the total variance. Available K and aryl sulfatase were the highest weighted variables in PC$_5$ but they were highly correlated ($r = 0.51; P = 0.05$). To reduce redundancy, only available K was retained because of its higher weighted loading in PC$_5$ and ease of estimation. Available B was selected from PC$_6$.

The importance of dehydrogenase activity as an indicator of soil microbiological quality in the initial oxidation of organic matter has been emphasized by others and also observed that dehydrogenase was a good indicator in their capacity of a soil to store nutrients and the content of organic C (Chaudhury et al., 2005; Masto et al., 2007). CEC values ranged between low and medium in magnitude considering the values found in soils of tropical and subtropical countries Basak (2011) established that a CEC value of 14.9 C mol (+) kg$^{-1}$ was ‘optimum’ for Inceptisols for harvesting 80% yield potential of a rice-based cropping system. The mean value of CEC of the studied soil was less than this ‘optimum’ value. This justified its occurrence as one of the main parameters for soil quality in Inceptisols.

2.7 Assigning Scores to the Observed MDS variables

After the MDS selection process, each MDS variable observed value was transformed into a value between 0 and 1 using scoring functions. Andrews and Caroll (2000) used non linear scoring functions with Y axis ranging from 0 to 1 and the X axis representing arrange of site dependent scores for that variable. The actual shape of the decision function either a sigmoid curve with an upper asymptote, a sigmoid curve with a lower asymptote or some variation on a bell shaped curve was indicator dependent. Accordingly they assumed an upper asymptote to total N and extractable Ca, lower asymptoteto bulk density and midpoint optimum for pH, nitrate N , extractable Zn and WHC (Karlen et al., 1994).This assignment of scoring functions both curve shape and X axis range assumed value judgements on the part of the user(Andrews and Caroll,2000).
Many scoring functions are widely used in economics as utility functions (Norgaard, 1994) in multi objective decision and management sciences as preference functions (Miller, 1970; Kenney and Raiffa, 1976) and is systems engineering as a tool for modeling (Wymore, 1993).

Using Wymore’s Standard scoring functions (SSF) scores were assigned to the observed values of MDS using specific algorithms developed by Wymore (1993). Using algorithm of SSF–3

\[
\text{Score} = \frac{1}{1+(B-L)/(V-L) \wedge (2*S* (B +V- 2*L))} \text{where } V = \text{ or } < B
\]

And

\[
\text{Score} = \frac{1}{1+(B - (2B-U))/V- (2B -U) \wedge (2*S* (B +V- 2*(2B-U))(2B -V))} \text{where } V>B
\]

L = Lower threshold value
U = Upper threshold value
S = Slope of the curve
B = Base value and
V = Observed value

Doran and Parkin (1994) suggested that the soil quality could be quantified by using regression equations that described relationships between the various soil quality indicators and the soil quality functions identified by Larson and Pierce (1994). Due to lack of regression equations Karlen et al., (1994 a and b) adopted Standardized Scoring Functions (SSFs) using a system engineering approach (Wymore, 1993) to assess changes in soil quality.

To quantify relationships between soil quality indicators and soil functions, Karlen et al., (1994 a and b) selected three SSFs (Standard Scoring Functions) to normalize indicators data. The score functions were (1) more is better (SSF3, 0–1); (2) optimum (SSF 4, 0–1–0) and (3) more is worse (SSF9, 1–0). Numerical values for each soil quality indicator were converted into unit less scores ranging from 0 to 1. The score for each indicator was calculated
after establishing lower threshold limits with published values (Karlen and Stott, 1994) or expert opinion.

According to Masto et al., (2007), the success and usefulness of a soil quality index mainly depends on setting the appropriate critical limits for individual soil properties. They stated that the optimum values of soil quality could be obtained from the soils of undisturbed ecosystems (Warkentin, 1996; Arshad and Martin, 2002), where soil functioning is at its maximum potential to provide critical values. They fixed the thresholds for each soil quality indicator based on the range of values measured in natural ecosystems or in best–managed systems and on critical values available in the literature. After finalizing the thresholds, they transformed the soil property values recorded into unit less scores (between 0 and 1), using the equation:

\[
\text{Non-linear score (Y)} = \frac{1}{1+e^{-b(x-A)}}
\]

Where \(x\) is the soil property value, \(A\) the baseline or value of the soil property where the score equals 0.5 and \(b\) is the slope. Using the equation, they generated three types of standardized scoring functions as i) ‘More is better’, ii) ‘Less is better’ and iii) ‘Optimum’ as defined in earlier studies (Karlen and Stott, 1994; Hussien et al., 1999; Glover et al., 2000).

Numerical weights for each soil quality indicator are multiplied by indicator scores calculated through the use of the standardized scoring functions that normalize indicator measurements to a value between 0 and 1.0. Scoring curves are generated from the following equation (Wymore, 1993):

\[
\text{Normalized score (v)}: \frac{1}{[1 + ((B-L)/(x-L)^2S(B+L-2L)])}
\]

where \(B\) is the baseline value of the soil property where the score equals 0.5, \(L\) is the lower threshold, \(S\) is the slope of the tangent to the curve at the baseline, \(x\) is the soil property value. Using the scoring curve equation, three types of standardized scoring functions typically used for soil quality assessment can be generated: (1) ‘More is better,’ (2) ‘Less is better,’ and (3) ‘Optimum.’ The equation defines a ‘More is better’ scoring curve for positive slopes, a ‘Less is
better’ curve for negative slopes, and an ‘Optimum’ curve when a positive curve is reflected at the upper threshold value. ‘More is better’ curves score soil properties that are associated with improved soil quality at higher levels. Aggregate stability, for example, plays a key role in a soil’s ability to resist structural degradation due to wind and rain (Kemper and Rosenau, 1986). Total nitrogen, cation exchange capacity (CEC), organic carbon, microbial biomass carbon (MBC) and nitrogen (MBN), and earthworm populations would also be scored with a ‘More is better’ curve. ‘Less is better’ curves score soil quality indicators, such as bulk density, that indicate poor soil quality at high levels. Higher bulk densities of compacted soils result in decreased root development and infiltration rates leading to poor plant growth and the potential for runoff of surface water (Arshad et al., 1996). ‘Optimum’ curves score those properties that have an increasingly positive influence on soil quality up to an optimal level beyond which their influence is detrimental. The presence of nitrate in the rooting zone, for example, is essential for plant growth and fruit development. Its presence at high levels, however, increases the potential for groundwater contamination (Doran et al., 1996). Other soil quality indicators such as porosity, water-filled pore space, extractable phosphorus, pH, and electrical conductivity (EC) would be rated using this type of curve.

For positive slopes, the equation defined a ‘More is better’ scoring curve; for negative slopes, a ‘Less is better’ curve; and for the combination of both, an ‘Optimum’ curve has been defined. They converted the numerical values for each soil quality indicator into unit less scores ranging from 0 to 1. The score for each indicator was calculated after establishing lower threshold limits, baseline values and upper threshold limits. Threshold values are soil property values where the score equals one (upper threshold) when the measured soil property is at most favorable level; or equals zero (lower threshold) when the soil property is at an unacceptable level. Baseline values are soil property values where the scoring function equals 0.5 and equal the midpoints between threshold soil property values. Baselines are generally regarded as minimum target values.
Shahid et al., (2013) conducted a long term field trial with rice-rice cropping system and Aeric Endoaquept soil at CRRI, Cuttack observed that MDS can be transformed using nonlinear scoring curves to obtain scores varying between 0 and 1, and these scores can then be used to derive a SQI.

2.8 Assigning weightages

For determination of soil quality index though integrative method the score value of each indicator is multiplied with weightage. There are different ways by which weightages for different parameters can be determined. Two ways are commonly used. Expert opinion and value judgment

In an experiment Masto et al., (2007) reported that the soil functions can be weighted according to the relative importance of each function in fulfilling the management goals based on expert opinions. All the soil functions were weighted according to the relative importance of each function in fulfilling the goals of maintaining soil quality in India, as suggested by experts (an advisory team of scientists from soil physics, chemistry, microbiology and soil fertility disciplines). Sustaining crop productivity is the major goal of long-term fertilizer strategies, particularly in a developing country like India. This function, therefore, received the highest weighting (30%). Nutrient supplying capacity of the soil also received a significant weighting (20%) in view of the likely nutrient deficiencies in many of the farmers’ field in developing countries (Sanchez and Jama, 2002). The above two functions are not independent of one another. Water relations and resistance to degradation are also very important for achieving the goals of sustainable soil management, thus they together were given a 50% weighting. The value of each function was determined from a set of soil quality indicators. These indicators were also weighted on the basis of the expert opinion panel, published literature and statistical tools such as regression and principal component analysis.

2.9 Assessment of Soil Quality Index (SQI)

After transforming the MDS variable into scores for each observation, Andrews and Carroll (2000) used additive index where they added the score
values to get a cumulating SQI. They compared the SQIs for the different management practices by calculating means, standard deviations, student’s t at $\alpha = 0.05$ and ANOVA for each treatments SQI score. The SQI values obtained by them indicated that for both the Alfisol and Ultisol sites the component management had the best soil quality.

Instead of using an additive index, where the scores were simply added, Andrews et al., (2002) used an integrative index. Each PC explained a certain amount (%) of the variation in the total data set. This percentage divided by the total percentage of variation explained by all PCs with eigen vectors >1, provided the weighted factor variables chosen under a given PC. They then summed the weighted MDS variable scores for each observation in the following formula:

$$\text{SQI} = \sum_{i=1}^{n} W_i \times S_i$$

Where $W$ is the PC weighting factor and $S$ is the indicator score. They compared the calculated SQI treatment means using ANOVA and student’s t at $\alpha = 0.10$ and assumed that higher index scores meant better soil quality or performance of soil functions. Using this formula, they demonstrated that soil quality indices for the manure and compost systems were significantly lower than the organic system but significantly higher than the conventional treatments. These results supported the SQI outcomes of Karlen et al., (1999).

This method is being used widely in recent soil quality assessment studies (Hazra et al., 2004; Mandal, 2005; Sharma et al., 2005, 2008, Chaudhury et al., 2005, Masto et al., 2007).

In a study, to determine soil quality, Masto et al., (2007) used the model primarily described by Karlen et al., (1994) with some modification, which is given as follows:

$$\text{Soil quality index (SQI)} = q\text{we}(wt) + q\text{wms}(wt) + q\text{r}sd\text{ (wt)} + q\text{rbd}(wt) + q\text{pns}(wt) + q\text{scp}(wt)$$
Where qwe is the rating for the soil’s ability to accommodate water entry, qwms to facilitate water movement and storage, qrsd to resist surface degradation, qrbd to resist biochemical degradation, qpns to supply plant nutrients, qscp to sustain crop productivity and wt is a numerical weighting for each soil function. These were set according to the function’s importance in fulfilling the overall goal of maintaining soil quality.

Armenise et al., (2013) showed that the MDS indicators were transformed into unit less combinable scores ranging from 0 to 1 (where 1 represents the optimum level for the indicator), accounting for their contribution to soil functions. The equation proposed by Wymore (1993) was used to generate three forms of scoring curves: more is better (a sigmoid shaped curve with an upper asymptote), less is better (a sigmoid shaped curve with a lower asymptote), and optimum (a bell shaped curve).

Chaudhury et al., (2005) reported the MDS variables for each treatment were transformed by using scoring functions. The SQI was calculated by using weighing factors for each scored MDS variable according to the formula:

\[
\text{SQI}= \sum S \times 0.799 \times S(\text{DHA}) + 0.799 \times S(\text{Available P}) + 0.799 \times S(\text{MWD}) + 0.139 \times S(\text{total N})
\]

Where S is the score for the variable and the coefficients are the weighing factors derived from the PCA. The organic system along with chemical fertilizer received the highest SQI value. The mean weight diameter of aggregates contributed maximum to the soil quality index (42.2%) followed by available P (29.6%), DHA (19.9%), and total N (8.3%), respectively. By considering 100% NPK + FYM as ideal treatment (SQI = 100), the relative soil quality explained that if there were exclusion of FYM, the soil quality (SQ).

Mohanty et al., (2007) recorded that soil quality in rice-wheat cropping system is governed primarily by the tillage practices used to fulfill the contrasting soil physical and hydrological requirements of the two crops. and observed that Soil Quality Index (SQI) values of 0.84 to 0.92, 0.88 to 0.93 and
0.86 to 0.92 were found optimum for rice, wheat and the combined system (rice + wheat), respectively.

Sharma et al., (2008), in a long term study conducted in rainfed Alfisol of sorghum – mung bean system reported that irrespective of conventional and reduced tillage, the sole organic treatments out-performed in aggrading the soil quality to the extent of 31.8 % over control whereas, the conjunctive nutrient use treatments aggraded the soil quality by 24.2 to 27.2 %, and the sole inorganic treatment could aggraded only to the extent of 18.2 % over unamended control. The extent of percent contribution of the key indicators towards soil quality index (SQI) as presented was: microbial biomass carbon (MBC) (28.5%), available nitrogen (28.6%), DTPA- Zn (25.3%), DTPA- Cu (8.6%), HC (6.1%) and MWD (2.9%).

Shahid et al., (2013) reported that improvement in soil physical and chemical as well as in biological activity of low land rice soil through continuous application of chemical fertilizers along with FYM resulted in a greater SQI and enhanced sustainability.

A collaborative study coordinated by Mandal (2005) indicated that cultivation without any fertilization (control) or only with N caused a net degradation of soil quality. Cultivation even with application of balanced NPK could hardly maintain such quality at the level where no cultivation was practiced. Only integrated use of organic and inorganic sources of nutrients could aggrade the system, Manna et al., (2007) compared the fertilizer treatments in a long-term study for 30 Years in Alfisol (Typic Haplustalf) Ranchi, India. They reported that yield increased with time for NPK +FYM and NPK + lime treatments in wheat. Biological soil health indicators such as Soil Microbial Biomass Carbon (SMBC), nitrogen (SMBN) and acid hydrolysable carbohydrates (HCH) were greater in NPK + FYM and NPK + lime as compared to other treatments. Findings of this study suggested that continuous use of NPK + FYM or NPK + lime would sustain yield in a soybean – wheat system without deteriorating soil quality. Soil degradation
occurs due to nutrient depletion, soil structure degradation, acidification and sub-optimal addition of organic and inorganic fertilizer to soil.

Shahid et al., (2013) working on rice-rice system at CRRI, Cuttack reported that the contributions of DTPA-Zn, Avail-N and SOC to the SQI were substantial and ranged from 59.4 to 85.7% in NPK+FYM and control, respectively.

Shri Ram et al., (2016) reported greatest SQI under 100% NPK + FYM (3.11 and 3.54) followed by 150% NPK (2.72 and 2.95), whereas it was least with the control (1.64 and 1.71) during over the years and in the 41st year, respectively, suggesting increase in NPK fertilizer level or addition of FYM is quite effective in maintaining SQI. Results are in conformity with the findings of Sharma et al., (2004), Katkar et al., (2012), and Li et al., (2013). The enhancement of soil quality due to either increase in fertilizer level or inclusion of FYM might be ascribed to rapid accumulation of residual nutrients in soil. Moreover, organic system along with 100% chemical fertilizers enhanced SQI by 14.33–43.32% and 35.63–43.32% over that observed for other 100% NPK treatments during 1972–2013 and in the 41st year, respectively. When different inputs were included with recommended dose of fertilizers, SQI was found to decrease in order of FYM > Zn > P > S > K, whereas among the treatments it was NPK + FYM > NPK + HW = NPK + Zn > NP > N. On the other hand, when FYM, Zn, P,K, S, and K were omitted from the fertilizer schedule over the years, the SQI decreased by 30.2, 16.5, 11.2, 2.7, and 0.8%, respectively.

Masto et al., (2007) developed the soil quality index (SQI) across various nutrient management in long-term fertilizer experiment and reported that the SQI ratings ranged from 0.552 (Unfertilized control) to 0.838 for the combined NPK fertilizer plus manure treatment. Comparisons among treatments indicated that SQI increases associated with the combined (NPK+ manure) treatment were distributed as follows: N (1.7% increase), P (7.8%), K (14.4%), Zn (4.8%) and manure (15%). The control (-11.4%) and N alone (-5.1%) resulted in degradation compared to a reference soil (no
fertilizer/manure, no crop) and NP alone or sub-optimal rates of NPK were on the verge of degradation. Chaudhury et al., (2005) reported from a LTFE of rice-wheat-jute cropping system that the mean weight diameter of aggregates contributed maximum to the soil quality index (42.2%) followed by available P (29.6%), DHA (19.9%), and total N (8.3%), respectively.

Sharma et al., (2015) conducted of long-term experiment comprising tillage and consumptive nutrient use treatments under sorghum-mung bean system during 1998-05 on SAT Alfisol (Typic Haplustalf) at the CRIDA, Hyderabad. The conjunctive nutrient-use treatments improved soil quality by 24.2 to 27.2 per cent and the sole inorganic treatment by 18.2 per cent over the control. The percentage contribution of the key indicators towards the SQI was: MBC (28.5%), available N (28.6%), DTPA-Zn (25.3%), DTPA-Cu (8.6%), HC (6.1%) and MWD (2.9%).

In India work on assessment of soil quality started only recently with the implementation of National Agricultural Technology Project (NATP) during 2000. Works started in 8 different centres located in the states of West Bengal (BCKV and CRIJAF), Orissa (OUAT), Assam (AAU), Andhra Pradesh (CRIDA & ANGRAU) and Uttar Pradesh (BHU) with BCKV in West Bengal as the lead center and others as co-operating centers where the results of long term experiments on dominant cropping systems of the region were used for the study. Standard methods already used by Andrews et al., 2002 were used for selection of MDS and quantification of soil quality. The MDS were selected entirely through a statistical frame work from a large set of variables drawn from physical, chemical and biological domain and both linear and non linear scoring functions were used for assigning scores. The soil quality index values were calculated through integrative approaches. All the centres reported that INM practices involving FYM maintained better soil and crop quality than other management practices. Most of the results have been published in Annual reports and bulletins. In Orissa Rout et al., (2004) compared 3 different methods of integrative indexing (Andrews et al., 2002), component integrative
indexing (Hussain et al., 1999) and integrative indexing (Andrews et al., 2002) through Wymore’s algorithm scoring approach (Wymore, 1993). The results clearly demonstrated differences in soil quality of among differently manured treatments which were in the order of 100%NPK+FYM > 100%NPK > 100%NP > 100%N.

Singh (2006) in India recently suggested nine indicators such as soil depth, texture, slope, organic matter, available N, available P, available K, CEC, and pH to evaluate soil quality under integrated nutrient management at farm situation. He calculated the soil quality index of each indicator separately by multiplying weight of indicators with marks allotted to the observed value. In his study he suggested weights to the indicators on the basis of existing soil conditions, cropping pattern, agro climatic condition and prevalence of flood so that all weights is normalized to 100%. He also divided all the indicator values into 4 categories and assigned marks of 4, 3, 2 and 1 to these classes depending on their suitability for crop growth. Through this study he showed improvement in soil quality under both farmers’ practice and INM practice. Soil quality under INM trial was improved by 12-19 units as compared to 7-9 units of farmer’s practice of farming. His results were however more speculative and based on assumptions.

2.9.1 Over all Soil Quality Index

In a study Hussain et al., (1999) calculated and over all soil quality index from functional components giving equal weightage to the three functional components they could clarify different responses to the critical soil functions and could provide a comprehensive assessment of soil quality. These functional components were used to identify soil management problems which were considered important for sustaining or improving the soil resources.

2.10 Relative Soil Quality Index

By considering 100% NPK + FYM as ideal treatment (SQI = 100), the relative soil quality explained that if there were exclusion of FYM, the soil quality would decline by 19.35%. Furthermore if FYM and potassium fertilizer
were excluded, the SQ would decline to 25.81%: similarly if FYM, potash and phosphorus fertilizer were excluded, the SQ would decline by 56.68%.

Kusuma (2008) has established the quantitative relationship between Relative Soil Quality Indices (RSQI) and functional goal such as long term average yields and Sustainability Yield Indices (SYI) of sorghum and mung-bean system. The simultaneous contribution of the key indicators towards functional goals has also been studied under sorghum - castor system in rainfed Alfisol using multiple regression functions. These relationships help in predicting the crop yield from a given value of RSQI and quantitative contribution of indicators towards long term crop yields and SYI. While working with biological soil health, Ghoshal (2004) proved that different biological indicators contributed differently towards explaining biological soil health for different cropping systems.

Chaudhury et al., (2005) working on soil quality reported that the organic system along with chemical fertilizer received the highest SQI value. The mean weight diameter of aggregates contributed maximum to the soil quality index (42.2%) followed by available P (29.6%), DHA (19.9%), and total N (8.3%), respectively. By considering 100% NPK + FYM as ideal treatment (SQI = 100), the relative soil quality explained that if there were exclusion of FYM, the soil quality (SQ) would decline by 19.35%. They reported a decline by 56.7% in the SQI for no manure and fertilizer compared to NPK+FYM treated plots in a long-term rice–wheat–jute system.

Although some research reports have recently established some conceptual frameworks for assessing soil quality, there are so far no reliable practical methods. Literature reviewed above suggest that for a particular agro-eco region suitable indicators of soil quality need to be identified, screened for a MDS and used for assessing relative indices. Finally these indices need to be validated by correlating with the goal functions of the soil to test the suitability of the method used.