Chapter 2

REVIEW OF LITERATURE

Soil is considered as the most essential resource for sustained quality of human life and related activities (Gajbiye and Mandal, 2006). But, increasing land use intensity without adequate and balanced use of chemical fertilizers, and with little or no use of organic manures have caused severe fertility deterioration of our soils resulting in the decline of crop quality and productivity, which ultimately leads to social ill health. Since the management of soil forms the basis for sustainable system of productive agriculture, and soils differ in their productivity, differential management practices depending on soil properties, rainfall, availability of water for irrigation and cropping systems are found essential (ICAR, 2011). Soil fertility is usually affected by both natural (climate, biosphere, parent material, topography and time) and artificial factors (management practices such as fertilization, manuring, green – manuring, crop rotations etc.), and hence evaluation of soil fertility in an agricultural field is an important aspect in the context of sustainable agricultural production. So this part mainly reviews the important studies conducted on soil fertility status of various agro ecosystems, spatial variation of soil fertility and soil mapping at state, national and global levels.

2.1. Soil fertility scenario

Soil fertility status with respect to basic soil properties and available macro and micro nutrients are mainly reviewed under this section.

2.1.1. Basic properties and macronutrients

Abroad

In Kissi District of south- western Kenya, Stoorvogel *et al*. (1993) reported the NPK balance of land use systems as 112 kg N, 3 kg P, and 70 kg K ha^{-1} yr^{-1}. The results of sensitivity analysis revealed that changing mineralization rate and soil N content had an important impact on the N balance. Varying slope gradient and length, soil erodibility, land over and the enrichment factor for eroded material affected all nutrients.

In Philippines, most of the area investigated in rice land had a high inherent fertility potential, and were rated suitable for intensive rice production. But 97% of the land had limitations due to one or more nutrients (Dobermann and Oberthur, 1997). Low availability of K, P, and Zn occurred on 54%, 64% and 63% of the land respectively, whereas low S status was found only in minor areas.

In Nepal, Regmi and Zoebisch (2004) reported better soil fertility status (with respect to N, P, K and OM) in Bari than in Khet land. The pH of soil was found slightly low and more acidic in Khet than in Bari land. Higher application rate of farmyard manure and less crop intensity resulted Bari land more fertile than Khet land. Another study by Khadka *et al*. (2016) in Nepal also revealed acidic reaction of soils, low status for OM and S. On the other hand, medium status reported for K and Ca and, high status for P and Mg. The studies by Khan *et al*. (2017) in the soils of Kanchanapur district in Nepal revealed that they were slightly acidic to neutral in reaction, low status of EC and, low to high levels of organic carbon. Hundred per cent of samples showed high in organic carbon, 55.2% medium and 54.8% high in available N, and most of the samples high in P, while 34.32% samples low, 58.20% medium and 7.46% high in available K.

In Ethiopia, according to Kebede and Yamoah (2009) soils of northern highlands were deficient in N and P. But the soil fertility status in the highlands of south-east were slightly acidic to neutral, low to medium in OM and exchangeable bases and, moderate in both total N and available P. Those soils were low to moderate in fertility requiring quite reasonable management (Belachew and Abera, 2010). Another study reported by Hailu *et al*. (2015) in Ethiopia revealed that soils of wheat fields in vertisols of central were deficient in N, P and S, and the same was ascertained by plant analysis. The nutrient deficiencies identified in this study were due to either inherently low availability of these nutrients in the soils or as a consequence of continuous intensive cropping without applying fertilizer or manure containing these nutrients. The results of this study showed the need for further studies in the deficient areas for determining wheat response to balanced fertilization.

In Swaziland, total N, exchangeable bases, P fractions and available P were assessed in the 0-30 cm layers of soils in the low, mid and high land zones by Haque and Lupwayi (2003). The results revealed that soils in the low land had significantly higher Ca and

Mg, and in the midland lower N content. The soils were generally deficient in N but had adequate Ca and Mg especially in the low land.

In Bangladesh, according to Hassan *et al*. (2017), most of the soil parameters in the Tista flood plain had positive directions towards fertility development due to farming methods, which included soil testing, crop rotation and cropping pattern based fertilizer recommendations, and integrated pest management. They concluded that the OM and total N content were low, but increased slightly from 1996 to 2016.

India

Increasing concern about the sustainability of Indian agriculture because of deterioration in soil fertility prompted to evaluate the fertility status of soils at national, and also at region and state levels. Ghosh and Hasan (1976) rated Indian agricultural soils as medium, high and low in available K to the extent of 42, 38 and 20% respectively. According to same reports by Anonymous (2001), Indian soils were rated as low, medium and high to the extent of 6, 45 and 49 per cent in available P, and 52, 39 and 9 per cent in available K respectively. On the other hand, according to Ghosh and Hasan (1979), the available P status in Indian soils were 46% low, 52% medium and 20% high. Out of 363 districts in India, high status of P was reported only in Himacal Padesh (2 districts) and in Rajasthan (3 districts), and the soils were categorized as 49.3% low, 48.8% medium and 1.9% high (Hasan,1996). According to Motsara (2002), out of 3,650,004 soil samples collected from India, per cent of samples which fell in low, medium and high categories were 63, 26 and 11 for available N; 42, 38, 20 for available P; 13, 37 and 50 for available K and 40, 35 and 25 per cent for available S, respectively. On the contrary, Hasan (2002) categorized K status in India's agricultural soils as 21% low, 51% medium, and 28% high and cautioned that 72% of India's agricultural areas representing 266 districts needed immediate K fertilization. The reports of Sharma and Kumar (2003) indicated that soils of agricultural lands of mid hill soil zones in India were medium to high in available N, low to medium in available P and low to high in available K. But, according to Tandon (2004), about 63, 44, 21 and 37 per cent of Indian soils were low in available N, P, K and S, respectively. The soil fertility of

22,948 soil samples from farmers' fields in India were tested by kit method to find out available P and pH during 1985-99. The pH of 80.35 % of the samples ranged between 8.0 - 8.5 and 90.30 % of samples had available P less than 5 ppm (Rehman *et al*., 2000). Pathak (2010) classified the soils into three categories i.e., low, medium and high, and nutrient indices were calculated for soils of different states. In some states like, West Bengal, Gujarat and Tamil Nadu, N fertility increased, while it declined in Orissa and Kerala. In the remaining states, the N status remained almost same from 1967 to 1997. The available K status in Indian soils resulted shift from medium to high in 60-70s and after that medium to low. Red, lateritic and shallow black soils have undergone K fertility depletion. Recent isolated studies even in medium deep and deep black soils indicated a shift of K status from medium to low. Crops grown on these soils were found to suffer from K deficiency. The K deficiency in crops grown on these soils was further aggravated by imbalanced K use by farmers (Naidu *et al*. 2011). According to Jayaprakash *et al*. (2012), arecanut growing soils of India were neutral to alkaline in reaction and with desired levels of EC. The status of macro nutrients (N, P, K and S) in majority of the samples ranged from medium to high.

In Himachal Pradesh, Thakur *et al*. (1971) found that the cultivated soils of Sreeraj and Karsog blocks in Mandi district were medium in available N and low in available P and K. But Verma *et al*. (1976) reported the cultivated soils of Kangra region of Himachal Pradesh were low in available N, P and K. Another study (Anonymous, 1988) revealed as medium in available N, low in available P and medium in available K. Ghosh and Hasan (1980) reported that available N status of soils of hill regions of India including Himachal Pradesh were high in available N, while those of plains were low to medium in its content. Verma and Tripathi (1982) reported that available N content in Una and Hamirpur districts varied from 113 to 228 kg ha^{-1} while it ranged from 295 to 503 kg ha^{-1} in Kangra, Mandi, Bilaspur, Shimla and Shirmour districts of Himachal Pradesh. Verma *et al*. (1985) characterised the soils of Kangra, Kulu, Mandi and Sirmour areas of Himachal Pradesh and reported that both the available P and K ranged between 2.69 - 28.22 kg ha^{-1} and 4.26 - 1507 kg ha^{-1} respectively. According to Raina (1988) the citrus growing soils of Paonta valley in Himachal Pradesh were low in available N, medium to high in available P and medium in available K. Another study by Kaistha and Gupta

(1993) indicated that exchangeable Ca and Mg in sub humid temperate high lands of Himachal Pradesh varied from 3.7 to 15.3 and 0.1 to 4.2 cmol (p+) kg^{-1} soil respectively. Sharma *et al*. (2002) reported that soils of Fatehpur block in Himachal Pradesh were low to high in available N and P, low to medium in available K and sufficient in exchangeable Ca and Mg. Exchangeable Ca in the soils of North-West Himalayas were reported as medium to high (2.2 to 10.5 cmol (p+) kg^{-1}) by Gupta and Tripathi (1989), and the status of exchangeable Mg as medium to high (0.7-10.5 c mol kg^{-1}) soil by Gupta and Tripathi (1996).

In Karnataka, according to Korikanthimath *et al*. (2000), the soils of cardamom plantations in Kodagu district were acidic in nature (5.0-6.6) with high organic carbon, medium to high in available N, low in available P and low to medium in available K content. The OC content was correlated positively and significantly with available N. Another study by Binitha *et al.* (2009) revealed that the nutrient status of Karnataka was optimum in relation with physiographic position and cropping pattern. Due to intensive irrigated agriculture practices in the area, the nutrient status did not follow any distinct trend with respect to physiographic units and crops grown. The soils of maize growing areas of southern transition zone of Karnataka were with low fertility status of N (1.6, < 1.73), high status of P (2.46, > 2.33) and medium status of K (2.2, 1.73-2.33), with respect to Parker's nutrient indices (Shetty *et al*., 2008). According to Pujar *et al*. (2010), in the grape growing soils of Bijapur district in Karnataka, pH ranged between 7.2 and 8.8, EC (0.18 to 1.75 dS/m), OC low to high (0.23 to 1.01 kg/ha) and the available N in the lower range (45 to 337.5 kg/ha). The soil fertility status of 20 seed production areas (SPAs) located in different seed zones of Karnataka indicated great variation among SPAs in various soil properties viz., pH, OC, available N,P and K (Gunaga *et al*., 2011). According to Pulakesi *et al*. (2012), the soils of farmers' fields in Karnataka were slightly acidic to alkaline in nature with low organic matter content, low available N, low to medium P, low to medium K and low to high S. Sannappa and Manjunath (2013) explored the fertility status of soils in five selected regions (H.D. Kote, Madikeri, Sakaleshpur, Shimoga and Sirsi) of the Western Ghats of Karnataka. The pH and EC of soils varied between 5.25 - 7.83, 0.03 - 0.28 m.mhos/cm, respectively. OC and available N were significantly high. The soils of Madikeri region had higher available P (34.34 kg/ha) and it was lower in Sirsi region (9.45 kg/ha). Both Madikeri and Sakaleshpur regions recorded highest K content of 717.0 kg/ha with least being in Sirsi region (90.0 kg/ha). The correlation co-efficients worked out for chemical properties of soils established non-significant relationship among them, except for OC, wherein it showed significant ($P \leq 0.01$) positive relationship with available N content of soils.

In Punjab, the study by Verma *et al*. (2005) revealed wide variation in fertility status of soils developed on various landforms in Mansa district and the soils were low in available N, low to high in available P and medium to high in available K.

In Maharashtra, the average N content in the soils of 70 acid lime orchards in western Vidarbha region ranged between 398.57 kg ha^{-1} and 270.12 kg ha^{-1}; P between 43.47 and 35.98 kg ha^{-1}; K between 328.30 and 227.92 kg ha^{-1}; Ca between 23.50 and 21.58 cmol (p +) kg $^{-1}$ and Mg between 12.94 and 10.43 cmol (p +) kg $^{-1}$ (Panchbhai *et al*., 2006). According to Survase *et al*. (2011), most of the areas in Maharashtra were fertile in nature and low and very low fertility of soils were noted only in some pockets. The physiography, climate and agricultural activities have greatly influenced the nutrient status of soil. Specific fertilizers and organic matters were recommended for nutrients deficient areas, which help to keep the balance of nutrients and to restore the fertility of soils. Desmukh (2012) reported that the soils of Ahmednagar district in Maharashtra were alkaline with higher EC and low to medium status of OC. Improper agriculture practices, intensive farming, monoculture type of cropping pattern and over irrigation were responsible for degradation of soil fertility.

In Goa, the soils of cashew gardens were acidic (slight to moderate) and non saline. Available N varied from low (108 kg/ha) to high (945 kg/ha), available P from low (16.12 kg/ha) to high (18.2 kg/ha) and K from 44.8 to 291.2 kg/ha (Belurkar and Yadawe, 2011).

In Tamil Nadu, 86.5% of coastal soils of Nagapattanam were low and 13.5% medium in N, 100% low in P and 100% medium in K (Arokiaraj *et al*., 2011). Srinivasan and Poongothai (2013) reported that the soils were neutral to moderately alkaline and non-saline in nature in Tamil Nadu. Almost all samples analyzed were deficient in N, while the macronutrients varied from low to high levels.

The soils of agricultural lands of Sandhari Nala watershed were neutral to slightly alkaline, non saline and deficient in N, P and K (Nigam *et al*., 2014).

In Assam, Baruah *et al*. (2013) reported that soils of tea garden belts were acidic in nature in all seasons. Medium SOM, medium-to-high available N and available P and low availability of K revealed that soils were not sufficiently fertile for crop production. Depending on the above soil properties, the study area was grouped in to six fertility classes as MMML, MMHL, MMMM, MHHL, MHHM, and MMHM.

In Andhra Pradesh, according to Singh and Mishra (2012), the soils of Varanasi were low in OC, available N and P but medium in K. Among the samples, 62 % were deficient in available S and a significant positive correlation existed between OC and available N, P, K and S.

Deficiency of available N and P, and adequacy of available K were noted in the two transects in the Aravalli mountain ranges and Malwa plateau by exam in a total of eight pedons. (Singh and Rathore, 2013).

In Chaattisgarh, Awanish *et al*. (2015) reported that in Raipur district 72 % of the samples studied belonged to the category low and 28 % medium with respect to N. The per cent of sample category of P under low, medium, and high were 70, 29 and 01 respectively and those of K were 0, 17 and 83 respectively.

In West Bengal, the soils of the Chotanagpur plateau were lateritic and acidic in nature, and 80 % of the area were with low in available P (Ghosh, 2015). Simultaneously, Pandit and Mukherjee (2016) also reported non-availability of essential plant nutrients to the crop in acidic soils in alluvial zone of West Bengal. The soils of this zone was characterized by low OC and P, and high available K.

In Banka district of Bihar and Dumka District of Jharkhand, Pandiaraj *et al*. (2017) evaluated soil fertility status of four different tasar growing regions and the results revealed that soil reaction in the study area varied from slightly acidic to slightly alkaline with pH values ranging from 5.18 to 7.58. Nutrient index value of organic carbon was high in all the places except in Digal Pahari. On the contrary, available N, P and S were with low index in all the places. Fertility rate of available K was high in most of the places.

In Kashmir, the soils under different agro climatic zones of Ladakh district were alkaline in reaction (pH 7.6 to 8.2). EC was highest (0.23 dSm^{-1}) at Pattan and least at Kargil (0.08 dSm^{-1}). Pattan soils were rich in OC with an average value of 1.0 %. Varied results were obtained with respect to available N, the highest being recorded at Pattan. Pattan recorded maximum available P (22.45 kg ha^{-1}) while highest S (53.40 kg ha^{-1}) was at Kargil (Dar *et al*., 2016). On the other hand, the soils of the grape orchards of Kashmir were medium in available N and P. All the soils were high in available K, Ca and Mg (Bhat *et al*., 2017).

Parker' S Soil Nutrient index

In order to compare the levels of soil fertility of one area with those of another, it is necessary to obtain a single value for each nutrient. The nutrient index was introduced by Parker *et al*. (1951). Ramamurthy and Bajaj (1969) modified the index classification as 1.67 for low, 1.67- 2.33 for medium and > 2.33 for high, to avoid underweightage to the medium categories. The nutrient indices in the soils of maize growing areas in southern transition zone of Karnataka was low (1.6) for N, high for P (2.46) and medium (2.2) for K (Shetty *et al*., 2008). But, the soils of Varahi River basin in the western part of Karnataka were characterized as low-medium-low (LML) category based on the nutrient index calculated with respect to available organic carbon (1.393), available P (1.857) and available K (1.321) (Ravikumar and Somashekar, 2013).

Based on the nutrient indices, the soils of Karnataka were acidic to alkaline in reaction, saline in nature, low to medium for N, medium to high for P, high for K, low for S, medium to high for Ca, high for Mg. Zn and Fe were deficient, Mn deficient to high, and Cu sufficient to excess levels (Denis *et al*., 2016).

The nutrient index in black soils of Madhya Pradesh revealed high fertility for Mn and B, medium for Cu, Fe and S, and low for Zn (Chouhan *et al*., 2012).

In Utter Pradesh, based on Parker's soil nutrient index, the soils were low in fertility for N, medium for P and K (Kumar *et al*., 2013).

In Punjab, Singh *et al*. (2016) reported highest nutrient index values for OC (1.88) and P (2.62) in vegetable cropping systems, and K (2.42) in rice – wheat system in Kapurthala district.

Kerala

According to Pathak (2010), there was a decreasing trend in the N status in Kerala. In Kerala, the total K removal by major crops is reported as 0.279 mt against total addition of 0.072 mt through fertilizers, with a negative K balance of 0.206 mt, and consequently the K reserve of the soils of the state depleted (Srinivasarao *et al*., 2011).

Simultaneously, another study by Dinesh *et al*. (2014) found high accumulation of P in Kerala due to over-fertilizing or adding too much manure. In soils with high P levels, significant amount of soluble P could exist in the run-off water from these sites and significantly impact water quality in nearby streams and lakes. Studies revealed that the concentration of P in run-off, and potential P transport to surface and groundwater increased when P application rates exceeded crop requirement. Similarly, Bastin *et al*. (2014) evaluated the soil fertility status out of 246 soil samples from different cropping systems of 41 villages in Thrissur district. The results revealed high content of P and K, medium OC and adequate levels of all micronutrients.

According to Mini *et al*. (2015), the soils were extremely acidic to slightly acidic in coconut based cropping systems of Onattukara sandy soils. The soil nutrient index value for available N was medium and those for available P and K were high and low respectively. Extensive soil acidification, excess levels of P and wide spread deficiencies of Ca, Mg, B and Zn were the major limitations to crop production in this region. B deficiency was reported in 77 per cent of the soil samples and deficiency of Ca and Mg in 85 per cent of samples.

Pathak (2010) found that during the years of 1967, 1977 and 1997, the index values of N were decreasing (2.11, 1.7 and 1.66), increasing tendency for P (1.1, 1.7 and 2.35) and not much change for K (1.0, 2.0 and1.98) in Kerala. Among the seventeen states in India, a drastic high change of P was occurred in Kerala. But there was an increasing tendency for N, P and K during the above three years on considering at national level.

2.1.2. Micronutrients

Abroad

In Ethiopia, soils of northern highlands were deficient in micronutrients (Kebede & Yamoah , 2009). According to (Hailu *et al*., 2015), the soils of wheat fields in central highlands of vertisols in Ethiopia were deficient in Zn and B

In northern Guinea and Sudan savanna zones, Oyinlola and Chude (2010) reported deficiency of B in all the soils (20 samples) while Zn in few samples. The content of other micronutrients were adequate in all the samples.

Studies conducted by Noor *et al*. (2013) in citrus orchards in Pakistan revealed that Zn marginal in 54.17 % and adequate in 45.83 % samples. Similarly, B was marginal in 83.33 % and adequate in 16.67 % samples. However, Cu, Fe and Mn were adequate in 100 % samples.

The soils of paddy growing areas of Malaysia were low in available B and all the soils had available B below 5 ppm irrespective of depth and location. Available Boron was revealed a positively correlated with OC and negative correlation with soil pH (Saleem *et al*., 2010).

In Nepal, Khadka *et al*. (2016) reported high status of Mn and Fe in the agricultural soils.

India

Singh (2001) reported that 12, 5, 49 and 3 per cent soils of India were deficient in Fe, Mn, Zn and Cu, respectively. Analysis of 2.52 lakhs surface soil samples collected from different parts of India revealed the predominance of Zn deficiency in divergent soils. Of these samples, 49, 12, 4, 3, 33 and 41% soils were deficient in available Zn, Fe, Mn, Cu, B and S respectively. The magnitude of Zn deficiency varied widely among soil types and with the various states. Coarse textured, calcareous, alkaline or sodic soils having sandy texture soils with high pH and low in organic matter were generally low in available Zn (Singh, 2004). The report from agricultural land of Sandhari Nala watershed in India revealed that the soils were critical in the levels of Zn, Cu and Fe (Nigam *et al*., 2014).

According to Mahajan (2001), the soils of Mandi district in Himachal Pradesh was high in DTPA extractable Fe, Mn, Zn and Cu. On the contrary, Sharma *et al*. (2002) reported that soils of Fatehpur block in Himachal Pradesh were deficient to sufficient in available micronutrients cations.

In Andra Pradesh, Srinivasarao *et al*. (2011) evaluated the emerging micronutrient deficiencies under continuous cropping with diversified nutrient management options covering a wide variety of soils and climate. After 20-30 years of long-term cropping, fertilization and manuring, most of the soils were found deficient in available Zn. Most of the food grains produced on those soils were also low in Zn concentrations and widespread Fe and Zn malnutrition problems found in human populations.

In Maharashtra, the study on soil fertility status of Ahmednagar district revealed that the available B ranged from 0.02 to 14.42 ppm. Boron was high in salt affected soils, which were located in the downstream part of Pravara River (Deshmukh., 2012).

In Karnataka, one hundred and fifteen soil samples (0-30 cm) taken from the farmers' fields were analyzed for the status of micronutrients. The available micronutrients such as Zn, Fe, Cu and Mn were deficient in 88 %, 72 %, 54 % and 51 % of samples respectively (Pulakeshi *et al*., 2012).

In the two transects in the Aravalli mountain ranges and Malwa plateau, a total of eight pedons were examined in the field by Singh and Rathore (2013). The micronutrients such as Fe, Mn and Cu were found sufficient and Zn deficient in the soils of both transect. Micronutrients were found relatively higher in soils of Malwa plateau compared to soils of Aravalli mountain ranges.

In Tamil Nadu, Arokiaraj *et al*. (2011) reported adequacy of Fe and Zn in 97 % and 53 % of samples, and deficiency of Mn and Cu in 100 % and 45 % respectively in coastal soils of Nagapattanam district. Srinivasan and Poongothai (2013) from their studies concluded that out of 21 soil samples, micronutrients were in sufficient category in most cases and few of them indicated low suitability for agriculture purposes in Tamil Nadu.

In Uttar Pradesh, Ali and Lakhan (2013) reported widespread deficiency of Zn in alluvial soils of Aligarh district.

In Andhra Pradesh, a crop nutrient survey was conducted in 54 mandals covering 150 rice fields in Karimnagar district by Ravikumar and Somashekar (2013) and 50 %, 26 % and 2 % of the soils were rated as deficient in available Zn, Fe, Mn respectively, while Cu was in adequate levels.

In Jammu and Kashmir, the extractable Fe, Cu and Mn were high in all the sampled sites, while Zn was low in 26.66 %, medium in 70 % and high in 3.34 % of sites. Hot water soluble B was low in 80 % and medium in 20% sites. (Nazif *et al*., 2006). Similarly, It was observed that majority of soils of grape orchards in Kashmir were high in available Fe, Mn and Zn and medium in available Cu, B and Mo (Bhat *et al*., 2017).

2.2. Spatial variation of soil fertility

The variations in soil properties may be affected by topographic position characteristics, erosion, vegetation history, weather conditions, and previous farming practices. Geostatistical methods can provide reliable estimates at unsampled locations provided that the sampling interval resolves the variation at the level of interest (Kerry and Oliver, 2004). Spatial prediction techniques, also known as spatial interpolation techniques, differ from classical modeling approaches.

Geostatistics is concerned with detecting, estimating and mapping the spatial patterns of regional variables and centered on the modeling and interpretation of the semivariogram. This instrument distinguishes variation in measurements separated by given distances (Goovaerts, 1997). Semivariogram models provide necessary information for kriging, which is considered to be an accurate and adequate method for spatial interpolation and evaluation of soil properties (Jabro *et al*., 2010).

Most soil spatial variability studies carried out in diverse temperate countries, e.g., UK (Blackmore *et al*., 1998), Belgium (Geypens *et al*., 1999), Denmark (Heisel *et al*., 1999), Netherlands (Verhagen, 1997), Germany (Domsch and Wendroth, 1997), USA (Cambardella and Karlen, 1999), provided very precise information for site-specific recommendations.

Precision farming can be considered a new crop management system, in which inputs are limited to where they are needed. In recent years, many scientific efforts and economic resources have been spent on measuring the spatial variability of crop yield and for the distribution of seeds or soil nutrients, with the aim of minimizing pesticide use and optimizing crop yield (NRC, 1999). Spatial variability drives precision agriculture because soil parameters with little or no spatial dependence will not be conducive to site-specific management and be managed on the average (Pierce and Nowak, 1999).

2.2.1. Basic soil properties and macronutrients

Abroad

In China, Son *et al*. (2003) studied the spatial and temporal variability of soil properties and changes of soil quality in a hill regions using geostatistical methods. Soil samples of 0-15 cm depth were collected within 105 locations from 112 ha field during 1985 and 1997. Soil properties resulted large variability with the highest coefficient of variation being observed for available P, the lowest for soil pH. Over the 12 year period, a significant decrease of soil organic matter appeared with original land use patterns of wasteland and paddy field, whereas other properties showed no significant changes. According to another study by Jing *et al*. (2014) in China, the spatial variability of pH, OM, total N and available K exhibited medium spatial variability and the coefficients of variations were 12.54 %, 40.14 %, 40.0 % and 40.0 % respectively. Available P exhibited strong spatial variability, and the coefficient of variation was 102.13 %. The spatial variation of pH, OM, total N and available K fit the index mode and the spatial variation of available P fitted with the spherical model. Total N, available P and available K were greatly affected by soil structural factors, while pH and OM were affected by both structural and random factors. But the experimental semi variogram developed in the paddy soils of south China showed moderate spatial dependence for all selected parameters. Spatial distribution maps were derived by kriging interpolation. The paddy fields were characterized by high concentrations of soil OM, total N and available N. The pH values decreased widely comparing with the data reported by the

National Soil Survey, especially in south-east China (Liu *et al*., 2014). According to the study by Li *et al*. (2016) in China, among the ordinary kriging, inverse distance weighted, global polynomial and local polynomial prediction methods, the accuracy was highest by using ordinary Kriging interpolation method to predict the spatial distribution of soil nutrients.

In Brazil, the study on spatial dependence using geostatistics revealed that all semi variograms were well structured with a relatively large nugget effect. Total C, total N, pH in H_2O and pH in KCl semi variograms were best fitted by spherical models. The maps were processed using GIS and the study field was divided into zones with similar homogeneity. The selected zone could now be subjected to different treatments, once the natural initial conditions were well known, and also be used as a baseline in carbon sequestration projects within the scope of the Kyoto Protocol's clean development mechanism (Cerria *et al*., 2004)

In Iran, soils varied in their non-exchangeable K content and their ability to supply K+ to crops. The geostatistical analyses indicated a generally moderate degree of spatial dependence in extractable K. By contrast, the release rate (slope) of parabolic equation showed random, pure nugget variance indicating no spatial correlation at this scale of observation. The spatial distributions of the exchangeable K prior to K application and the initial rate of K+ release could be used for variable rate application to maintain an adequate K status for crop production (Jalali, 2007). On the other hand Fathi *et al*. (2014) carried out a study in Iran to determine the degree of spatial variability of soil chemical properties, soil texture, and variance structure. The spatial distribution and spatial dependence level varied within location. P had the shortest range of spatial dependence (49.50 m) and percentage of calcium carbonate equivalent had the longest (181.94 m). All parameters were strongly spatially dependent. The results demonstrated that within the same field, spatial patterns might vary among several soil parameters.

In Sri Lanka, the semivariograms were calculated for the soil properties of paddy growing tract by Nayanaka *et al*. (2010). The available P, clay content and OM exhibited a high spatial structured variability whereas a medium structured variability was observed for soil pH. Pure nugget effect was observed for exchangeable Ca, which indicated a dominance of a random variation. The observed spatial dependencies of soil properties could be used to support spatial sampling for detailed soil mapping and thereby it was suggested that management practices such as fertilizer application, irrigation and tillage operations could be fine tuned within fields scale to maximize rice crop production while minimizing the detrimental effects on environment.

In Pakistan, Wasiullah *et al*. (2010) designed a model for spatial variability of soil properties and their mapping in semi arid district Kohat of Khyber Pakhtunkhwa province. OM content in the surface soil revealed a linear model. Content of K in the surface and sub soils were described by linear models revealing strong spatial patterns in surface and very poor structure in subsoil.

In Newzealand, Qiu *et al*. (2011) investigated the spatial variability of available nutrients and organic matter in soil. Results indicated that P and OM showed significant spatial variability. All measured variables except mineral N showed moderate to strong spatial dependence.

In Spain, Papadopoulos *et al*. (2013) studied the spatial distribution of soil properties for the implementation of a site-specific fertilization practice. Data were analyzed both statistically and geostatistically on the basis of the semivariogram. Results indicated that spatial distribution model and spatial dependence level varied both between and within locations. Parameters with strong spatial dependence (patchy distribution) would be more readily managed and an accurate site-specific fertilization scheme for precision farming developed.

In Nigeria, spatial analysis of the data in the fields of farmers under yam based cropping system of the north-central and south- east regions by Jemo *et al*. (2014) showed that the best fit semivariogram models for N and K were rational quadratic, and hole effect for available P. Relative nugget effect for total N and exchangeable K were 70 % and 45 % respectively. The available P in soil resulted a weak spatial dependence with RNE of 83 % and a range of 1.8 km. The moderate spatial dependence observed for N and exchange K recommended for developing a strategy for site specific management of N and K taking into account the structural and random factors dominant in the study areas. The management of P to improve yam production in north–south and south-east of Nigeria was generalized at regional scale, given the weak spatial dependence observed for this nutrient.

In Mexican territory, Cruz – Gardenas *et al*. (2014) evaluated the spatial prediction using 4400 soil samples for Ca, K, Mg, Na, OC, OM, EC, sodium absorption ratio and pH. With the use of geostatistical methods a layer was generated for each soil property after developing six different semivariogram models. The kriging was selected as the best semivariance method and exponential, pentaspherical and spherical models were selected with ordinary and universal kriging methods to spatially predict the soil properties. The results revealed moderate spatial dependence for all the above parameters except sodium absorption ratio.

India

Sen *et al.* (2007) studied the spatial variability in nutrient status, and used the data for site specific fertilizer recommendation, which positively impacted rice yields in farmer fields of India. Available nutrient status showed wide variation across the study area, which was associated with fertilization history and the cropping sequence adopted by individual farmers.

Reza *et al*. (2012) revealed the spatial variation of soil properties in Brahmaputra plains and developed the spatial structures using semivariogram. Soil properties showed large variability and greatest variation was observed in available P (86 %), and the smallest in pH (19 %). The semivariogram for all soil properties were best fitted by exponential models and showed a highest (2.7 km) range for OC and lowest (1.2 km) for available P. The nugget/sill ratio indicated a strong dependence for pH (12 %), moderate spatial dependence for available nutrients (53 – 72 %), and a weak spatial dependence for OC (77 %).

Choudhary *et al*. (2013) worked out the spatial distribution of OC stocks in the north eastern India and noted wide variation. According to Raghupathi and Srinivas (2014), the spatial variability in soil properties create problem for soil sampling in the mango orchards of India. The geo-statistical procedure of kriging was used for interpolation of grid data and to prepare contour maps. The spatial dependence was analyzed by semivariogram method. The coefficients of the semivariogram model viz. nugget effect, range and sill were estimated to understand spatial dependence. Most of the nutrient elements exhibited spatial variability and semivariogram model was different for different nutrient element.

In Punjab, Verma *et al*. (2005) reported a wide variation in the soil fertility status. The soils were low in available N and low to high in available P and medium to high in available K.

A study carried out to examine the spatial variation of soil fertility status of sugar cane field soil from bank of Hiranykeshi river from Gadhinglaj Tahsil revealed marked variation in nutrients levels at seven sites with Mg content was below the normal range (Sawant *et al*. 2013).

In Thripura, Tiwari *et al*. (2015) identified the technique of pedometric mapping to link SOC and soil SOC loss. The best-fit semivariogram model found for SOC was exponential model (R^2 = 0.90). The best fit semivariogram models for soil and SOC losses were spherical (R^2 = 0.95) and exponential (R^2 = 0.77) respectively.

In Karnataka, Patil *et al*. (2011) investigated spatial variability of soil properties of soil OC and available N in surface soils of 154 farmers' fields. OC content was low in majority of the area (683 ha), while it was medium in the remaining area (350 ha). The observed spatial variability in various soil properties that influenced soil fertility help farmers in making crop management decisions. Satish *et al*. (2017) quantified spatial variations in farmers' fields of Karnataka, and the respective thematic maps were prepared on the basis of ratings of nutrients.

2.2.2. Micronutrients

Abroad

In Pakistan, Wasiullah *et al*. (2010) developed a spherical model for Mn in the subsoil with a range of 20.19 km. Fe content was described by linear models with a poor structure in surface and strong spatial structure in subsoil. B content in both the depths was described by spherical models with a range of 15.70 km in surface soil and 4.32 km in the subsoil. The data on various measured soil properties and the semivariogram models developed were used to estimate the soil test values at unsampled locations using geostatistical technique of kriging.

In Ghana, Odoi *et al*. (2011) conducted a study to investigate the levels, sources, distribution and spatial variability of heavy metals (Cu, Mn, Cd, Pb, and Zn) in soils close proximity to an industrial area. The results indicated that the concentrations of all metals except Cd exhibited weak spatial autocorrelations (ratios ranging from 0.80 to 11.94) confirming that spatial variability was affected by the industrial effluent discharge.

In Pakistan, Noor *et al*. (2013) studied the spatial variability of micronutrients (Zn, Cu, Fe, Mn and B) in citrus orchards. The semivariogram analysis showed that Cu, Fe and B had strong, Zn moderate and Mn poor spatial structure, described by linear model. Computer generated maps using kriging technique showed that almost all the maps had some spatial variation in different micronutrient contents in the field.

In China, experimental semivariogram was developed in the paddy soils of southern region and moderate spatial dependence observed for all selected parameters. Distribution maps were derived by kriging interpolation. Correlation analysis revealed that rice yield was significantly negatively correlated with Zn (Liu *et al*., 2014).

In Ethiopia, the studies on the spatial variation of micronutrients in soils of different parts of southern region showed significant differences (except B) among districts and resulted moderate spatial dependences (Bulta *et al*., 2016).

India

The studies on spatial variation of soil properties are very few in India and none in Kerala. Raghupathi and Srinivas (2014) reported that the nugget/sill ratio was high for soil Zn when compared to plant Zn indicating that soil available Zn was less spatially dependent compared to plant Zn. The range indicated the bare minimum number of samples required to represent the entire heterogeneity within the fields in mango orchards of India. Shukla *et al*. (2016) prepared semivariogram for each micronutrient in the intensive agriculture soils of Gangetic plains of India and their main parameters were calculated. Zn, Cu and Fe resulted moderate spatial dependence with N/S ratio 60 %, 34 % and 37 % respectively. On the other hand, Mn revealed strong spatial dependence with a ratio of 19 %.

2.3. Soil fertility mapping

Considering the important role of soil fertility and nutrient management in the modern agriculture, the preparation of high-quality soil fertility map seems to be a crucial step in appropriate site-specific management for crop production. Kravchenco and Bullock (1999) examined the various methods of interpolation to determine the optimal interpolation method for mapping of soil properties. The soil data from 30 agricultural fields were analyzed for P and K. For the majority of the data sets, kriging with the optimal number of the neighboring points, a carefully selected semivariogram model, and appropriate log-transformation of the data performed better than IDW weighting. The most important way to gather knowledge about unsampled locations was to prepare soil maps through spatial interpolation of point-based measurements of soil properties (Santra *et al*. 2008).

2.3.1. Basic properties, macro and micronutrients

Abroad

According to Iftikar *et al*. (2010), GIS based soil fertility maps represented an alternative decision support tool, and village scale field study outlined a cost effective option of implementing improved nutrient management in large tracts of small scale farming systems in Asia.

In New Zealand, the map of soil pH in a vineyard created a continuous dataset that could be represented over a map of the entire study area. The method investigated included; Inverse Distance Weighting (IDW), Radial base Function (RBF) and Ordinary Kriging (OK) (Zandi *et al*., 2011).

In Brazil, soil profile data set at national scale (1:5,000,000) was constructed from the soil archives of Embrapa Soils, Rio de Janeiro and in the regional scale (1:250,000) from COMIGO Cooperative soil data set, Rio Verde. The mapping was done using Arc GIS 9.1 tools from ESRI (Prado *et al*., 2012).

In Mexican Territory, soil fertility maps were generated by Cruz-Gardenas *et al*. (2014). The soil properties were classified primarily as slightly low or medium according to their distribution throughout the study area.

In Nigeria, the results obtained from the GIS fertility maps revealed the acidic condition in majority of the area. The soils were non saline, low in N, low to high in OM, low in P and medium in K. The results showed that the fertility of the area was not so high, with majority of the nutrients having low to medium amounts (Aderonke and Gbadegesin, 2013).

India

For the first time in India, Linsley and Bauer (1929) prepared soil fertility maps on soil series basis. First systematic soil fertility map of Indian soils were published in 1967 by Ramamurthy and Bajaj (1969). At that time around 4% of samples were high in available P. Later, Sekhon *et al*. (1985) suggested soil series as a basis for soil fertility mapping. Soil fertility mapping and fertilizer recommendations made on soil series basis were more scientific than those on the basis of administrative units *e.g*. district, block etc. Chamuah *et al*. (1989) observed a considerable spatial variation in paddy responses to applied N, P and K in different soil series in India. Similar results were also reported in wheat by Naidu *et al*. (1988). Bhan *et al*. (2010) revealed the integrated use of Remote Sensing and GIS technology in several areas for sustainable agricultural development and management in India. The soil fertility map published in 2002 (Motsara, 2002) indicated that around 20% of soil samples were high in available P.

In Karnataka, the fertility maps were prepared for GLBC command area using Arc View 3.1 and spatial analyst using spline function for interpolation. Due to intensive irrigated agriculture practice in the command area, the nutrient status did not follow any distinct trend with respect to physiographic units and crops grown. Based on the overall assessment, the nutrient status in those soils were optimum (Binitha *et al*., 2008). Prabhavati *et al*. (2015) prepared the soil fertility maps in Karnataka and revealed that available K, S and Zn were distributed equally between low and medium classes despite K being medium and S low and Zn sufficient. The pH was slightly lower, OC and available N distinctly higher, and available P and DTPA extractable Cu lower in forest lands compared to agricultural lands. Land use did not influence available K and DTPA extractable Zn, Fe and Mn

In Madhya Pradesh, land evaluation for agricultural planning was carried out based on soil survey data using geographical information system (Bobade *et al*., 2010). The soil-based GIS data was compiled and interpreted for land use suitability and fertility assessment. Maps of fertility and land use suitability were generated from interpretative records. A crop suitability map for each agricultural land use was developed by combining the climatic and soil site factors for each crop.

In Odisha, soil fertility maps on 1:25000 scales were geo-referenced and digitized by using ArcGIS software. Thematic layers were developed for block boundaries to prepare the base map. Superimposing polygons of block units, the base map and soil fertility maps were prepared. These maps were integrated in GIS to generate a composite database of GPS based soil of Dhenkanal district. These maps were divided into 8 mapping units. Based on the generated soil fertility maps, the status of organic carbon, available N, P, K, and S were assessed (Misra *et al*., 2014).

Kerala

The GIS based soil fertility mapping and spatial variation studies have not yet been done in Kerala, except the mapping done by Bastin *et al.* (2014), which was an isolated study using very few geo-referenced samples. It is in this context, this comprehensive study was launched to develop a GIS based soil fertility mapping and assess spatial variation for site specific nutrient management practices in Thrissur district.