Research Article

Vertical Distribution of Plant Nutrients in Alluvial Soils of Aravalli Range and Optimization of Land Use

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ABSTRACT

The study area consists of the alluvial plains of Kothari River, which is the tributary of Banas and situated in Eastern Rajasthan Upland. The area surrounded by Aravalli hills and situated between 25^{0}01' and 25^{0}58'N latitude and 74^{0}01' and 75^0 28' E longitudes. Twelve pedons were selected for the study of available macro and micronutrients with the aim to sustain the better productivity and sustainability. Soils were classified as coarse loamy, mixed hyperthermic Typic Haplustepts on higher elevations and fine loamy, mixed hyperthermic Typic Haplustepts on lower part of landform. Soils were analyzed for the status of available nitrogen, phosphorus, potassium, iron, manganese, zinc and copper content in vertical as well as in horizontal direction. Nitrogen, phosphorus and zinc content decreased in horizontal direction from higher elevation to lower elevation while iron and copper showed a reverse trend. Almost all nutrient elements showed a decreasing pattern in vertical direction of the pedons except copper. Soil properties viz. silt plus clay, organic carbon, pH, electrical conductivity and calcium carbonate together contributed 56, 63, 34, 50, 62 and 44 per cent to the availability of phosphorus, potassium, iron, manganese, zinc and copper, respectively. Soils on upper rolling plain with annual precipitation of less than 600 mm can be utilized without further deterioration by planting erosion resistant crops like pulses or grasses with economically important trees, like; mango, guava and Aonla. The soils of lower plains are relatively more fertile with high AWC, 700 to 800 mm annual precipitation and appropriate proportions of soil separates imparts the opportunity to the farmers to grow high value vegetable crops like okra, bottle gourd, ridge gourd or cowpea in Kharif whereas cabbage, cauliflower, brinjal, tomato, potato, French bean or pea in Rabi season.

Keywords: soil fertility, macro and micronutrients, alluvial soils, land use plan, vegetables.

INTRODUCTION

Alluvial soils constitute the largest and most important soil group of India and contribute most to the agricultural wealth of the country. The soils are derived from the deposition of silt by the numerous river systems. They cover about 75 million ha in the Indo-Gangetic Plains (IGP) and Brahmaputra Valley and deficient in nitrogen (N), phosphorus and organic matter. Generally, alluvial soils range from near neutral to slightly alkaline in reaction. A wide variety of crops is grown in these soils. Sound Knowledge about soil fertility status is very much relevant for identifying constraints in crop husbandry for attaining sustainable productivity and facilitating agro-technology transfer programme. Alluvial soils are variable in texture, drainage and state of maturity. They are liable to flooding and the surface receives fresh additions of material, which are laid down in successive layers, often of different grain sizes. Some alluvial soils are poorly drained, even peaty, but others on levees and terraces are imperfectly or freely drained. As they are water deposited, many alluvial soils retain their layered nature, but older terrace soils gradually achieve maturity and come to resemble adjacent upland soils (*Bridges,* 1979).

The study area is rich in natural vegetation, which grows on the slopes of the Aravallis but excessive felling of trees has degraded these open forests. Tank water irrigation is most common. The area produces maize as the chief food crop during Kharif season but in irrigated areas, paddy is also grown. In the Rabi season, wheat, gram and oilseeds are the main crops. Some farmers are also growing vegetable crops like okra, tomato and bottle gourd. Papaya as a fruit crop is also being cultivated in scattered areas of the region. The total catchment area of the Banas river Basin is 45,833 km^2 according to the scale topographical maps (1:250,000) published by the Survey of India. Orographically, the western part of the Basin is marked by hilly terrain belonging to the Aravali chain.

Capability of soils to supply nutrient elements to the crops, environmental suitability, availability of water to irrigate and crop management technology are very important factors for making sustainable and optimized land use plan for alluvial soils. Shortage of rainfall followed by imperfect water harvesting techniques, course textured soils with low in macro and micronutrients, organic carbon and water retention capacity in Eastern Rajasthan Uplands are major crop production constraints. According to *Rattan* et al. (2009) the importance of micronutrients has been realized during the past four decades when widespread micronutrient deficiencies, particularly zinc and boron, were observed in most of the soils in our country, where intensive agriculture is practiced. Micronutrients are not only important for better crop productivity, but also essential for sustaining human and animal health. It is experienced that alluvial soils of Indo-Gangatic Plains with 15-20 per cent clay and larger portion of the silt are the most productive as these soils contain enough of clay to provide an adequate surface for interaction with water and nutrients, to have a friable structure beneficial for tillage and root growth (*Pal* 2003).

It is well known that without knowing the fertility status of alluvial soils, planning for optimized land use plan for the area is not possible. In view of necessity of adequate information the present study on alluvial soils of Eastern Rajasthan Uplands has been planned.

MATERIALS AND METHODS

The study area as shown in map (fig.1) is comprised of thirteen geomorphic regions. It is almost rectangular in shape. The north and south-western portion of the district is an open plain marked with a few hillocks rising intermittently. The south and north-eastern portion is occupied by undulating lands and hills. The eastern portion consists of an elevated plateau. There is a distinct hill range in the north-east corner which extends up to Jahazpur town.

Aravalli hilly ranges intersect the study area at several places. These hills are prominent in the south-eastern part in Mandalgarh Tehsil. Bijoliya-Mandalgarh region of the Bhilwara district is termed as Uparmal due to its situation on a plateau. The general altitude of the study area is about 380 meters above the mean sea level in plains of north. It gradually rises towards the western part of the district up to a general altitude of 500 meters above the mean sea level. The general slope of the study area is towards north-east.

The geology of the study area is quite complex. The soils almost underlined by Pre-Cambrean rocks, which consist of Bundelkhand gneiss, Banded gneissic complex, Aravalli system, composite gneisses, Delhi system and Vindhayans. The Bundelkhand gneiss is spread in extensive area, which comprises granites, and schist's out of which granite type is seen in the rocky area towards the adjoining Chittaurgarh district. The banded gneissic complex also cover extensive area in the south-eastern region while Aravalli system covering a wide area in the form of belts and comprises quartzite's, conglomerates, shale's, slates, phyllites and composite gneisses. The Delhi system comprises conglomerates occurring in the midst of the Aravalli schists and gneisses. The rock of Vindhyans comprises red, brown hard and flaggy sandstone, shale and limestone. From the mineral point of view the area is rich. The important minerals found in the district are mica, soapstone, garnet, asbestos, lead, zinc, copper, iron ore and building materials (*Singh* et al., 2006).

The mean annual air temperature (MAAT) varies between 25.6 ^{o}C and 27.1 ^{o}C. January is the coldest month (7.8 ^{o}C) and May is the hottest (41.5 ^{o}C). The moisture index (MI) ranges from -59.7 to -39.5, indicating semi-arid dry to moist condition. The relative humidity varies between 40 to 80 per cent. Average PET is 1380 mm. The precipitation is found greater >0.5 PET for 90-105 days. Length of growing period (LGP) ranges from 90-135 days in a year. The soil moisture and temperature regimes are Ustic and Hyperthermic, respectively.

In the present investigation, an alluvial plains of Kothari river of Bhilwara district surrounded by Aravalli hills was selected, having three rainfall zones *viz.,* Upper rolling plains: Moderately sloping hills with a mean annual rainfall <600 mm (P1 to P4), Middle sloping plains: Gentle to very gently sloping plain with a mean annual rainfall 600-700 mm (P5 to P8) and Lower plains: Very gentle sloping plain with a mean annual rainfall 700-800 mm (P9 to P12). The area situated between 25^{0}01' and 25^{0}58'N latitude and 74^{0}01' and 75^{0} 28' E longitudes. Twelve pedons were sampled for the study of macro and micronutrients status for optimization of land use.

All these three groups of profiles were situated approximately 50 km apart to each other from higher elevation (upper rolling plains) to lower elevation (lower plains). Four profiles within a group were selected for study and these were situated at a distance of 250 m and 500 m left and right side across the direction of river flow channel. Air dried soil samples were gently crushed with a wooden roller and passed through 2 mm sieve and analyzed for general soil properties with standard procedures (*Jackson,* 1973) and (*Page* et al.,1982). For available nitrogen alkaline potassium permanganate method (*Subbiah* and *Asija,* 1956) was adopted. Available phosphorous in soil was extracted with 0.5 M $NaHCO_3$ (pH 8.5) as described by *Olsen* et al. (1954) and color in the extract was developed using stannous chloride as described by *Jackson* (1973). Available potassium was extracted in neutral normal ammonium acetate as described by *Richards* (1954) and measured by flame photometer. Available iron, manganese, zinc and copper were extracted with 0.005 M DTPA (pH 7.3) and 0.01 M calcium chloride (*Lindsay* and *Norvell,* 1978) as described by *Page* et al. (1982) and estimated using Atomic Absorption Spectrophotometer.

RESULTS AND DISCUSSION

Generalized Physico-chemical characteristics

Soil colour varied from gray (10YR 5/1) to very dark brown (10YR 2/2). The soils of upper rolling plains were relatively shallower (120 cm) than middle sloping (126 cm) and lower plains (140 cm). Sequence of soil horizon development was A-B-C in all pedons except the soils of P6 and P10 where only A-C horizons were present. The soils of area were sandy loam to loamy sand. Sand was the dominating fraction (37-92 %) in the soils of all three plains. Among the plains, sand fraction was relatively higher (76.9 %) while silt (15.5 %) and clay (7.6 %) were lower in the soils of upper rolling plains. The soils of lower plains contained higher amount of silt (21.9 %) and clay (13.1 %) and lower sand fractions (65 %). The soils of middle slopping plain were moderate in sand, silt and clay fractions. An increasing trend of silt and clay fractions down the depth was noted in all three plains but it was more prominent in the soils of lower plains due to the process of eluviation and illuviation of soil materials. Value of pH and electrical conductivity was relatively lower (pH 7.29 & EC 0.17 dSm^{-1}) in the soils of upper rolling plain whereas higher (pH 8.10 & EC 0.60 dSm^{-1}) in the soils of lower plain but mean pH values were recorded maximum (pH 8.49) in the soils of middle sloping plains due to secondary accumulation of calcium carbonate. The level of EC was found within the safe limit and has no adverse effect on crop growth and production in Kothari river plains. Coefficient of variation was low (<15 %) in case of pH while high (>35 %) for EC in soils of all three plains. Data regarding range, average and covariance of generalized soil site characteristics in different plains are presented in table 2.

Essential Plant Nutrients

Availability of nitrogen, phosphorus, potassium and cationic micronutrients (DTPA extractable) in alluvial soils surrounding of Kothari river were studied and assessed in relation to impact of general soil site characteristics on nutrient availability. Status of available macro (N, P and K) and micronutrients (Fe, Mn, Zn and Cu) are presented in table 1.

Nitrogen

Nitrogen is a part of all living cells and is a necessary part of all proteins, enzymes and metabolic processes involved in the synthesis and transfer of energy. Nitrogen content varied from 104 to 357, 45 to 248 and 74 to 264 kg/ha with a mean value of 188, 135 and 141 kg/ha in upper rolling plain (P1-P4), middle sloping plain (P5-P8) and lower plain (P9-P12), respectively. Higher nitrogen content in upper rolling plain (P1-P4) was due to presence of higher organic carbon compared to other plains. Datta et al. (1990) also observed low nitrogen in lowlands as compared to overlying counterparts. The mean content of nitrogen in Ap layers was 290, 218 and 207 kg/ha while it was decreased in Bw layers to a mean value of 162, 120 and 128 kg/ha in upper rolling plain, middle sloping plain and lower plain, respectively. A gradual decrease of nitrogen was noted down the depth in all three plains and it was positively correlated with organic carbon content (r = 0.519**). It was also reported by Meena et al. (2006) in some surface soils of Tonk district of Rajasthan. A regression line was also fitted between organic carbon and available nitrogen content (fig. 2 A). Surface soils were found deficient in available nitrogen content in 10 pedons out of 12 pedons. Soils of alluvial plains of Kothari river were rated as low to medium in supply of available nitrogen.

Phosphorus

Phosphorus (P) is also an essential part of the process of photosynthesis, involved in the formation of all oils, sugars, starches, etc. Phosphorus content varied from 2 to 43, 2 to 45 and 1 to 13 kg/ha with a mean value of 11.4, 9.7 and 4.4 kg/ha in upper rolling plain, middle sloping plain and lower plain, respectively. Higher phosphorus content in upper rolling plain was due to presence of higher organic carbon as compared to other plains. The mean content of phosphorus in Ap layers was 27.3, 25.4 and 9.7 kg/ha while it decreased in Bw layers to a mean value of 6.4, 5.0 and 2.3 kg/ha in upper rolling plain, middle sloping plain and lower plain, respectively. A gradual decrease of phosphorus was noted down the depth in all three plains and it was positively correlated with organic carbon content (r = 0.596**) (Meena et al. 2006) while P_2O_5 was not significantly correlated with pH, EC and $CaCO_3$. A regression line was also fitted between organic carbon and available phosphorus (fig. 2 B). Soils of alluvial plains of Kothari river were also rated as low to medium in supply of available phosphorus.

Potassium

Potassium is absorbed by plants in larger amounts than any other mineral element except nitrogen and, in some cases, calcium. Potassium content varied from 103 to 732, 87 to 1160 and 108 to 466 kg/ha with a mean value of 235, 438 and 240 kg/ha in upper rolling plain, middle sloping plain and lower plain, respectively (Table 1). Higher potassium content in middle sloping plains was mainly due to presence of higher amount of micaceous minerals as compared to other plains while it was approximately identical in upper rolling and lower plains. The mean content of potassium in Ap layers was 407, 495 and 264 kg/ha while it was 190, 603 and 297 kg/ha in Bw layers in upper rolling, middle sloping and lower plains, respectively. It was observed that content of potassium decreased down the depth in upper rolling and lower plains while a reverse pattern was noted in middle sloping plain. The major contributor of potassium element in middle sloping plains was natural mica deposits that became more prominent down the depth of pedons while the soils of upper rolling plains and lower plains where potassium was mainly contributed by mica and associated minerals (Sharma et al. 2010) but some amount could also be attributed by decomposition of organic matter. Pal et al. (2005) also reported very important role of fine grained mica in potassium management in alluvial soils of Nepal. Available potassium was significant and positively correlated with organic carbon (r = 0.505**) and silt (r = 0.542**) while it was not correlated with clay content. A regression line was also fitted between organic carbon and available potassium (fig. 2 C). It is indicated that silt size particles were the major contributor of potash while clay contributed to a very little extent to crops and it is mainly due to weathering of biotite mica up to the stage of silt fractions. The soils of alluvial plains of Kothari river were rated as high in supply of available potassium.

Micronutrients

DTPA extractable micronutrients viz. Iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) are integral part of plant components. The data pertaining to the cationic micronutrients are presented in table 1.

Iron (Fe)

Iron content varied from 3.09 to 10.55, 2.96 to 8.64 and 3.87 to 9.23 mg/kg with a mean value of 5.32, 4.96 and 5.94 mg/kg in upper rolling, middle sloping and lower plains, respectively (Table 1, 2). The lowest value of Fe (2.96 mg/kg) was observed in the soils of Karanwas (P5) of middle sloping plain while highest Fe content was noted in the soils of Jalamali (P2) of upper rolling plain. On mean content basis Fe was maximum in the soils of lower plain.

Mean Value of DTPA-extractable Fe was 5.31, 5.60 and 6.93 mg/kg in Ap horizons and 5.50, 4.72 and 6.14 mg/kg in Bw horizons of upper rolling, middle sloping and lower plains, respectively. It can be inferred from the above data that DTPA extractable Fe content decreased slightly down the depth in middle and lower plains except the soils of upper rolling plain. This might be due to the difference in the distribution of silt, clay and carbonates in different plains. Sharma et al. (2007) also reported decreasing trend of available Fe from surface to subsurface horizons. A significant negative correlation was found between available iron and pH (r = - 0.420**), and calcium carbonate (r = - 0.355**) considering the soils of all the plains together. This might be due to the precipitation of Fe as $Fe(OH)_2$ or Fe-carbonate (Halder and Mandal, 1987) and/or conversion of Fe^{2+} to Fe^{3+} (Randhawa and Singh, 1997) at alkaline pH environment. Regression lines were also fitted between available Fe with pH (fig. 2 D) and calcium carbonate (fig. 2 E).

Lindasay and Norvell (1978) suggested 4.5 mg/kg of DTPA extractable iron as critical limit for available iron. Considering these critical limits the soils of four pedons (P1, P2, P4 and P5) out of total twelve pedons were found to be deficient in supply of iron. The data revealed that 75 per cent soils of upper rolling plain and 25 per cent soils of middle slopping plain were deficient in available Fe while the soils of lower plain were sufficient. These findings are in agreement with those of

Sharma et al. (2003) in soils of semi-arid region of Rajasthan.

Manganese (Mn)

The content of extractable manganese varied from 1.96 to 9.96, 0.88 to 8.64 and 3.25 to 10.33 mg/kg with a mean value of 5.41, 4.83 and 6.13 mg/kg in upper rolling, middle sloping plain and lower plains, respectively (Table 1, 2). The lowest value of Mn content (0.88 mg/kg) was observed in lower most layer in the soils of Lasaria (P7) of middle sloping plains while highest Mn content (10.33 mg/kg) was noted in upper most layer in the soils of Akola (P9) of lower plain. The mean value of Mn was maximum in the soils of lower plain.

A vertical distribution of Mn (mean value) indicated that 7.20, 6.34 and 6.76 mg/kg of Mn was present in Ap horizons and 5.13, 4.47 and 6.73 mg/kg in Bw horizons of upper rolling, middle sloping and lower plains, respectively. It can be inferred from the above data that DTPA extractable Mn decreased down the depth of pedons in two plains except the soils of lower plain where distribution was approximately uniform throughout the depth. Variation in Mn down the depth may be attributed to the difference in the distribution of organic carbon, silt plus clay and carbonates in different plains. Uniform distribution of Mn in lower plains could be due to organic matter in surface layer while silt plus clay in subsurface layers. Sharma and Chaudhary (2007) also reported decreasing trend down the depth of available Mn in Solan district of Himalaya. A significant negative correlation was found between available Mn and pH (r = - 0.288**), and calcium carbonate (r = - 0.323**). It could be due to the precipitation of Mn as hydroxides or carbonates (Halder and Mandal, 1987) and/or conversion of Mn^{2+} to Mn^{3+} or above at higher pH. A significant positive correlation was noted between Mn and organic carbon (r = 0.612**). Regression lines were also fitted between available Mn with pH (fig. 2 F), calcium carbonate (fig. 3 A) and organic carbon (fig. 3 B). Joshi and Dhir (1983) also found similar relationship.

Considering 2.0 mg/kg of DTPA-extractable Mn as critical limit for available manganese (Lindasay and Norvell, 1978) the soils of all three plains were sufficient in available manganese.

Zinc (Zn)

DTPA extractable zinc content ranged from 0.11 to 0.81, 0.08 to 0.98 and 0.07 to 0.37 mg/kg with a mean value of 0.35, 0.24 and 0.17 mg/kg in upper rolling, middle sloping and lower plains, respectively. A lowest value of Zn content (0.07 mg/kg) was observed in lower most layer in the soils of Akola (P9) of lower plain while highest value (0.98 mg/kg) was noted in upper most layer in the soils of Lasaria (P7) of middle sloping plain. Zinc was highest on mean content basis in the soils of upper rolling plain.

Vertical distribution of Zn (mean value) indicated that Ap horizons contained 0.58, 0.45 and 0.23 mg/kg while Bw horizons had 0.30, 0.22 and 0.14 mg/kg Zn in upper rolling, middle sloping and lower plains, respectively. DTPA-extractable Zn decreased with the depth of pedons in all the plains due to the difference in the distribution of organic carbon down the depth. Sharma and Chaudhary (2007) also reported decreasing trend of available Zn from surface to subsurface horizons. The study further revealed that organic carbon was the major contributor of available Zn. A significant positive correlation was noted between Zn and organic carbon (0.721**) while there was no relationship with other soil properties (pH, EC and $CaCO_3$). To some extent, organic matter reduces the pH of the soil locally which helps in increasing solubility of zinc besides its effect on weathering of minerals containing zinc products and organic matter decay may also have chelating effect on zinc and chelated zinc may become available to plants. Further, it is less subjected to fixation reaction. Regression line was also fitted between available Zn with organic carbon (fig. 3 D).

Takkar and Mann (1975) suggested limits of available Zn, as <0.6, 0.6-1.2 and >1.2 mg/kg of DTPA-extractable Zn for deficient, marginal and sufficient classes, respectively. Considering these critical limits, the soils of all three plains were found to be deficient in available zinc except three pedons (P3, P4 and P7), which were marginal in Zn supply. These findings are supported by those reported by Sharma et al. (2003) in soils of semi-arid region of Rajasthan.

Copper (Cu)

Copper content varied from 0.24 to 0.82, 0.24 to 2.28 and 0.41 to 1.55 mg/kg with a mean value of 0.57, 0.83 and 0.83 mg/kg in upper rolling, middle sloping and lower plains, respectively. A lowest value of Cu content (0.24 mg/kg) was observed in subsurface layer in the soils of Kalal Kheri (P3) of upper rolling plain and Sarano Ka Kheda (P6) of middle sloping plain while highest Cu content (2.28 mg/kg) was noted at the depth of 42-70 cm in the soils of Lasaria (P7) of middle sloping plains. On mean content basis Cu was equally available in the soils of middle sloping and lower plains.

The mean values of copper content down the depth was 0.49 (Ap)-0.62 (Bw), 0.84 (Ap)-1.17 (Bw) and 0.89 (Ap)-0.96 (Bw) mg/kg in upper rolling, middle sloping and lower plains, respectively. The data revealed that DTPA extractable Cu increased down the depth of pedons in all the plains. This might be due to the increased content of silt and clay down the depth that provides exchange sites to hold exchangeable forms of copper or presence of some Cu containing minerals down the depth. It can be concluded that silt and clay size fractions was the major contributor of available Cu. A significant positive correlation was noted between Cu and organic carbon (0.439**, fig. 3E), and silt (0.614**, fig. 3F). Similar relationship has also been reported by Dhane and Shukla (1995).

Lindasay and Norvell (1978) suggested 0.2 mg/kg of DTPA extractable Cu as critical limit for available copper. Considering these critical limits the soils of all three plains were found to be sufficient in available copper.

Soil properties and nutrient availability

Regression analysis of data revealed that the availability of macro (P_2O_5 & K_2O) and micronutrients (Fe, Mn, Zn & Cu) in alluvial soils of Kothari river plains depended on various soil properties viz. silt plus clay, organic carbon, pH, electrical conductivity and calcium carbonate content. All soil properties put together contributed 56, 63, 34, 50, 62 and 44 per cent to the availability of phosphorus, potassium, iron, manganese, zinc and copper, respectively. Phosphorus was mainly contributed by organic carbon (35 %) followed by clay fraction (10 %) while contribution of potash was maximum from silt fraction (29%). It was observed that iron availability was mainly controlled by soil pH (18%) and calcium carbonate (13%) while manganese availability was mainly influenced by organic carbon (37%) and calcium carbonate (10%). Availability of zinc found to be regulated prominently by organic carbon content (52%) whereas copper was mainly contributed by silt fraction (38%) and organic carbon (19%).

Optimization of land utilization

Soil erosion resistant crops like pulses or grasses with economically important trees, like; mango, guava and Aonla should be planted in the soils of upper rolling plain. Although, the fertility, coarse fragments, severe erosion excessive slope and low AWC, produce the environment that is not congenial for plantation. However, plantation of deep rooted fruit trees could be possible by digging the pit deep up to the rock. The excavated material should be mixed with the good soils along with proper fertilizers and manure. Irrigation of trees should be done time-to-time till their establishment. Plantation must be done at the time of onset of monsoon so that they can easily be established during the rainy season. These should be given proper protection from the grazing animals. The grasses should be planted in and around rolling topography to check the onslaught of erosion. After keeping it protected, for some years, the landscape will be in a position to produce fodder and fruits for the area and also the major constraint, erosion may come closer to the rate of soil formation. This will definitely help in initiating of pedogenetic development in soils of upper rolling plains of the river. In order to meet out the dietary need and food habit of the people, sorghum, Bajra and pulses depending on the onset of monsoon are recommended to grow in the soils of middle sloping plains (P5-P8) during Kharif season, whereas during Rabi, this should be cultivated for wheat alone or wheat and gram in combination. Maize can also be grown in middle sloping plains of the river system. After the harvest of maize, either mustard or gram alone or in combination may be grown in the interspaces. This will definitely help to meet out the partial demand of oil and pluses for the time being and help to reduce soil losses. Later on the planted trees will be ready for the fodder, fruit and timber. Groundnut, pigeon pea in Kharif, wheat, mustard and gram combination during Rabi, along with the trees of mango, guava, papaya, citrus and Aonla may be cultivated in the lower plain for optimizing land use. The soils of lower plain are relatively more fertile in respect to micronutrients status with high AWC, 700 to 800 mm annual precipitation and appropriate proportions of soil separates imparts the opportunity to the farmers to grow high value vegetable crops like okra, bottle gourd, ridge gourd or cowpea in Kharif whereas cabbage, cauliflower, brinjal, tomato, potato, french bean or pea in Rabi season depending upon the water available for irrigation to protect the crop from severe water stresses. Vegetables may be harvested every third day and sold in the local market or nearby city. Hybrid varieties of vegetable crops gave very good returns in terms of monetary forms to the growers and may become a regular revenue generating crop. Soils used exclusively for bajra or maize during Kharif while wheat in Rabi if the farmer don't have ample water delivery resources. However, the trees of guava, mango and

Aonla may be planted on the ridges or the boundary of the fields. These soils require careful application of soil water conservation techniques to restrict the losses through erosion and to maintain soil fertility for longer duration.

Although the soils of study area are low in fertility status but adoption of optimized land use plan and involvement of vegetable crops considering the soil capability may be a regular revenue generating source for the farming community associated with soils of lower plain. Plantation of deep rooted fruit trees could be done by digging the pit deep up to the rock and excavated material should be mixed with the good soil along with proper fertilizers and manure and adoption of drip irrigation system to irrigate may resolve problem of scanty water resources in soils of upper rolling plain.

Table 1: Status of available macro and micronutrients in soils

Depth	Horizon	Available macronutrients (kg ha^{-1})			Available micronutrients (mg kg^{-1})			
(cm)		N	P_2O_5	K_2O	Fe	Mn	Zn	Cu
Upper rolling plains with a mean annual rainfall <600 mm								
P1: Baniyon Ka Khera								
0-10	Ap	356.8	42.86	298.1	3.80	4.72	0.51	0.43
10_26	Bw1	208.5	9.44	151.8	5.50	5.26	0.81	0.76
26-46	Bw2	178.4	2.11	140.9	6.07	7.32	0.28	0.78
46-65	Bw3	148.6	3.30	168.0	4.97	5.91	0.29	0.66
65-80	Bw4	133.8	2.70	130.1	4.26	3.78	0.21	0.45
P2: Jalamali								
0-18	Ap	252.7	9.44	178.9	9.94	7.15	0.33	0.34
18-52	Bw1	237.8	3.90	124.7	10.55	5.07	0.11	0.48
52-90	Bw2	193.2	3.30	103.0	10.41	7.98	0.14	0.59
P3: Kalal Kheri								
0-16	Ap	282.4	34.73	731.8	3.42	6.96	0.67	0.69
16-47	Bw1	178.4	12.12	287.3	3.35	4.26	0.34	0.82
47-84	Bw2	148.6	12.00	238.5	3.79	3.83	0.29	0.70
84-140	Bw3	133.8	13.29	173.5	3.50	3.01	0.26	0.51
140+	Cr	118.9	12.00	135.5	3.09	1.96	0.22	0.24
P4: Dulkhera								
0-19	Ap	267.6	22.10	417.4	4.10	9.96	0.79	0.50
19-37	Bw1	163.5	10.71	319.8	4.06	5.25	0.25	0.56
37-75	Bw2	148.6	5.03	249.4	4.30	5.55	0.33	0.54
75-125	Bw3	133.8	3.90	200.6	5.11	5.81	0.26	0.65
125-170	Bw4	104.1	1.51	184.3	5.62	3.66	0.28	0.54
Middle sloping plains with a mean annual rainfall 600-700 mm								
P5: Karanwas								
0-17	Ap	237.8	22.63	346.9	3.90	5.74	0.40	0.67
17-30	A2	178.4	18.73	433.7	3.29	5.15	0.35	0.65
30-69	Bw1	148.6	3.30	520.4	4.03	6.19	0.26	0.89
69-96	Bw2	141.2	3.30	525.8	3.25	4.60	0.22	0.67
96-120	BC	133.8	4.50	618.0	2.96	3.05	0.27	0.46
120-140	C	104.1	6.95	661.3	3.05	3.10	0.11	0.39
P6: Sarano Ka Kheda								
0-18	Ap	148.6	24.23	140.9	4.82	4.90	0.11	0.47
18-50	A2	104.1	6.95	162.6	4.30	4.87	0.18	0.24
50-100	A3	95.3	6.95	162.6	4.30	4.75	0.14	0.45
100-140	A4	89.2	6.33	92.2	4.82	4.87	0.10	0.44
140-175+	A5	59.5	3.30	86.7	4.95	4.60	0.09	0.39

Continue…

Depth	Horizon	Available macronutrients (kg ha^{-1})			Available micronutrients (mg kg^{-1})			
(cm)		N	P_2O_5	K_2O	Fe	Mn	Zn	Cu
P7: Lasaria								
0-18	Ap	248.3	45.17	1160.1	6.10	8.64	0.98	1.65
18-42	Bw1	163.5	14.61	753.5	5.27	7.31	0.54	1.74
42-70	Bw2	89.2	4.50	1100.4	3.99	3.25	0.15	2.28
70-110	Bw3	44.6	2.70	1030.0	3.13	0.88	0.14	2.03
P8: Hamirgarh								
0-19	Ap	237.8	9.44	330.7	7.61	6.09	0.31	0.57
19-50	A2	133.8	2.11	189.7	8.64	4.50	0.08	0.74
50-73	Bw1	123.2	3.30	130.1	8.49	4.37	0.08	0.60
73-100	Bw2	118.9	3.90	146.4	6.61	6.09	0.09	0.72
Lower plains with a mean annual rainfall 700-800 mm								
P9: Akola								
0-19	Ap	223.0	13.29	168.0	6.95	10.33	0.12	0.61
19-45	A2	118.9	8.19	151.8	5.22	5.55	0.33	0.41
45-85	Bw1	104.1	2.11	157.2	4.04	5.95	0.13	0.77
85-125	Bw2	89.2	2.11	151.8	4.81	5.64	0.09	0.67
125-170	Bw3	74.3	0.93	157.2	5.14	6.38	0.07	0.54
P10: Akola								
0-20	Ap	148.6	9.44	119.3	6.53	4.69	0.23	0.57
20-50	A2	118.9	4.10	124.7	4.09	4.99	0.17	0.61
50-90	A3	104.1	3.30	130.1	4.94	4.24	0.13	0.72
90-125	A4	118.9	2.93	108.4	3.87	3.25	0.10	0.42
125-170	A5	104.1	2.11	162.6	5.08	4.66	0.16	0.71
P11: Akola								
0-17	Ap	193.2	12.01	466.2	7.36	6.15	0.37	1.36
17-38	Bw1	133.8	3.90	460.8	9.23	8.91	0.16	1.55
38-62	Bw2	118.9	1.51	444.5	7.60	10.11	0.11	1.12
62-100	Bw3	104.1	1.51	352.4	5.71	5.26	0.34	0.87
P12: Akola								
0-15	Ap	263.5	4.19	303.6	6.88	5.87	0.19	1.00
15-35	Bw1	223.0	3.93	281.9	8.52	8.03	0.12	1.47
35-75	Bw2	237.8	3.30	325.2	5.51	5.48	0.10	1.00
75-120	Bw3	74.3	0.93	341.5	4.75	4.85	0.11	0.66

Table 2: Mean, standard deviation, covariance and range of soil properties in soils of upper rolling plain, middle sloping plain and lower plain

S. No.	Soil Properties	Upper rolling plain (P1-P4)					Middle sloping plain (P5-P8)					Lower plain (P9-P12)				
		Mean	S.D.	C.V. %	Min.	Max.	Mean	S.D.	C.V. %	Min.	Max.	Mean	S.D.	C.V. %	Min.	Max.
1	Total Sand (%)	76.89	6.78	8.82	64.68	92.42	71.93	10.24	14.24	59.91	87.34	65.05	14.98	23.02	36.89	83.68
2	Silt (%)	15.52	6.44	41.53	1.58	27.65	18.42	10.3	55.9	4.61	32.99	21.89	12.42	56.75	6.52	50.3
3	Clay (%)	7.59	0.69	9.11	6	9.14	9.64	2.08	21.62	7.04	15.15	13.06	5.17	39.56	6.82	24.24
4	B. D. (Mg/m^3)	1.46	0.13	8.57	1.33	1.73	1.49	0.14	9.18	1.23	1.67	1.39	0.1	7.22	1.21	1.56
5	P. D. (Mg/m^3)	2.65	0.01	0.36	2.63	2.67	2.64	0.01	0.47	2.62	2.65	2.63	0.01	0.47	2.61	2.65
6	Porosity (%)	44.79	4.7	10.5	34.66	49.85	43.58	5.3	12.17	36.91	53.59	47.18	3.84	8.14	41.27	54.48
7	Soil Moisture at 33 Kpa (m^3/m^3)	0.15	0.06	37.73	0.07	0.26	0.22	0.09	40.03	0.07	0.35	0.24	0.07	30.36	0.102	0.34
8	Soil Moisture at 1500 Kpa (m^3/m^3)	0.07	0.02	31.04	0.03	0.12	0.1	0.05	56.08	0.04	0.24	0.09	0.04	44.06	0.03	0.16
9	AWC (profile depth)	2.23	2.05	91.95	0.31	7.5	3.47	1.87	53.83	1.14	7.54	4.28	1.9	44.42	1.51	7.78
10	pH	7.29	0.4	5.47	6.56	7.87	8.49	0.57	6.77	7.7	9.73	8.1	1.01	12.44	6.14	9.55
11	EC (dS/m)	0.17	0.08	46.19	0.05	0.34	0.37	0.21	55.76	0.09	0.89	0.6	0.52	86.52	0.1	1.56
12	$CaCO_3$ (%)	1.52	1	66.17	0.52	4.64	3.88	4.81	123.99	0.38	16.62	1.15	0.43	37.78	0.38	2.04
13	Organic Carbon (%)	0.31	0.18	58.34	0.09	0.93	0.3	0.28	95.81	0.07	1.34	0.26	0.17	64.73	0.07	0.67
14	Na (cmol(P^+)/kg)	0.17	0.1	62.49	0.04	0.38	0.44	0.39	88.55	0.01	1.48	0.85	0.83	97.89	0.02	2.24
15	K (cmol(P^+)/kg)	0.12	0.09	75.09	0.04	0.4	0.21	0.13	60.33	0.04	0.48	0.12	0.06	45.83	0.06	0.21
16	Ca (cmol(P^+)/kg)	3.82	0.58	15.09	2.64	4.61	3.6	1.35	37.64	1.79	7.07	5.27	3.23	61.34	2.08	12.57
17	Mg (cmol(P^+)/kg)	1.41	0.43	30.33	0.8	2.43	2.4	0.8	33.39	1.63	4.91	2.45	0.86	35.33	1.06	4.33
18	CEC (cmol(P^+)/kg)	5.65	0.73	12.89	4.23	6.95	6.95	1.26	18.15	5.06	10.33	9.15	3.05	33.32	4.75	15.68
19	B.S. (%)	97.79	0.56	0.57	96.8	98.6	95.67	0.92	0.97	94.5	98.6	94.72	1.41	1.49	92.1	97.1
20	ESP	2.99	2	67.05	0.88	8.67	6.47	5.46	84.36	0.1	20.98	11.14	10.87	97.56	0.2	31.4
21	N (kg/ha)	188	67	36	104	357	135	56	42	45	248	141	58	41	74	264
22	P_2O_5 (kg/ha)	11	11	100	2	43	10	11	111	2	45	4	4	83	1	13
23	K_2O (kg/ha)	235	149	63	103	732	439	349	80	87	1160	240	126	52	108	466
24	Fe (mg/kg)	5.32	2.44	45.82	3.09	10.55	4.96	1.75	35.28	2.96	8.64	5.94	1.53	25.74	3.87	9.23
25	Mn (mg/kg)	5.41	1.95	36.04	1.96	9.96	4.83	1.66	34.48	0.88	8.64	6.13	1.91	31.18	3.25	10.33
26	Zn (mg/kg)	0.35	0.21	58.03	0.11	0.81	0.24	0.21	86.76	0.08	0.98	0.16	0.09	54.41	0.07	0.37
27	Cu (mg/kg)	0.57	0.15	26.76	0.24	0.82	0.83	0.59	71.5	0.24	2.28	0.83	0.34	40.67	0.41	1.55

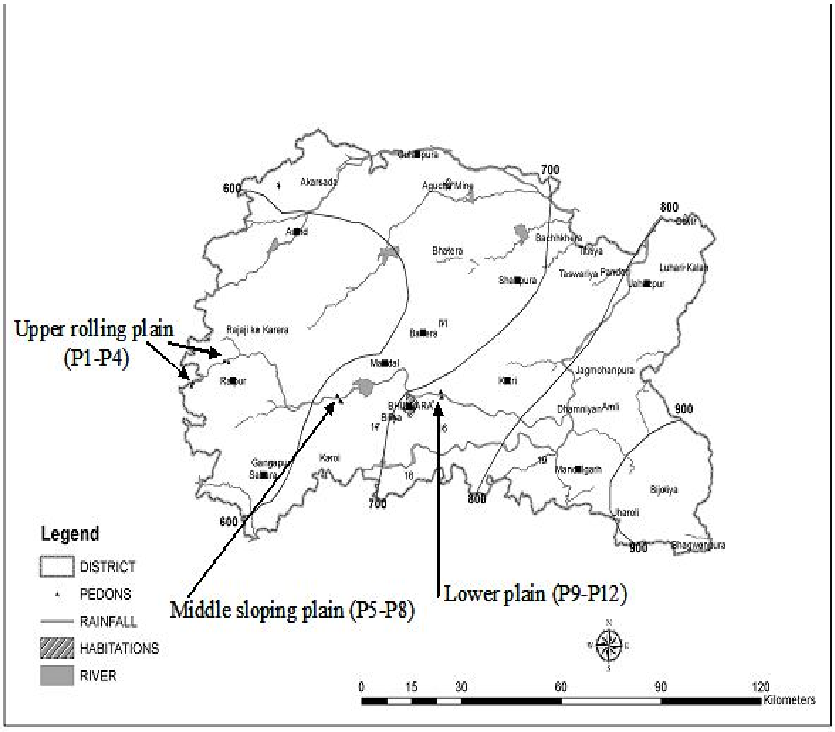
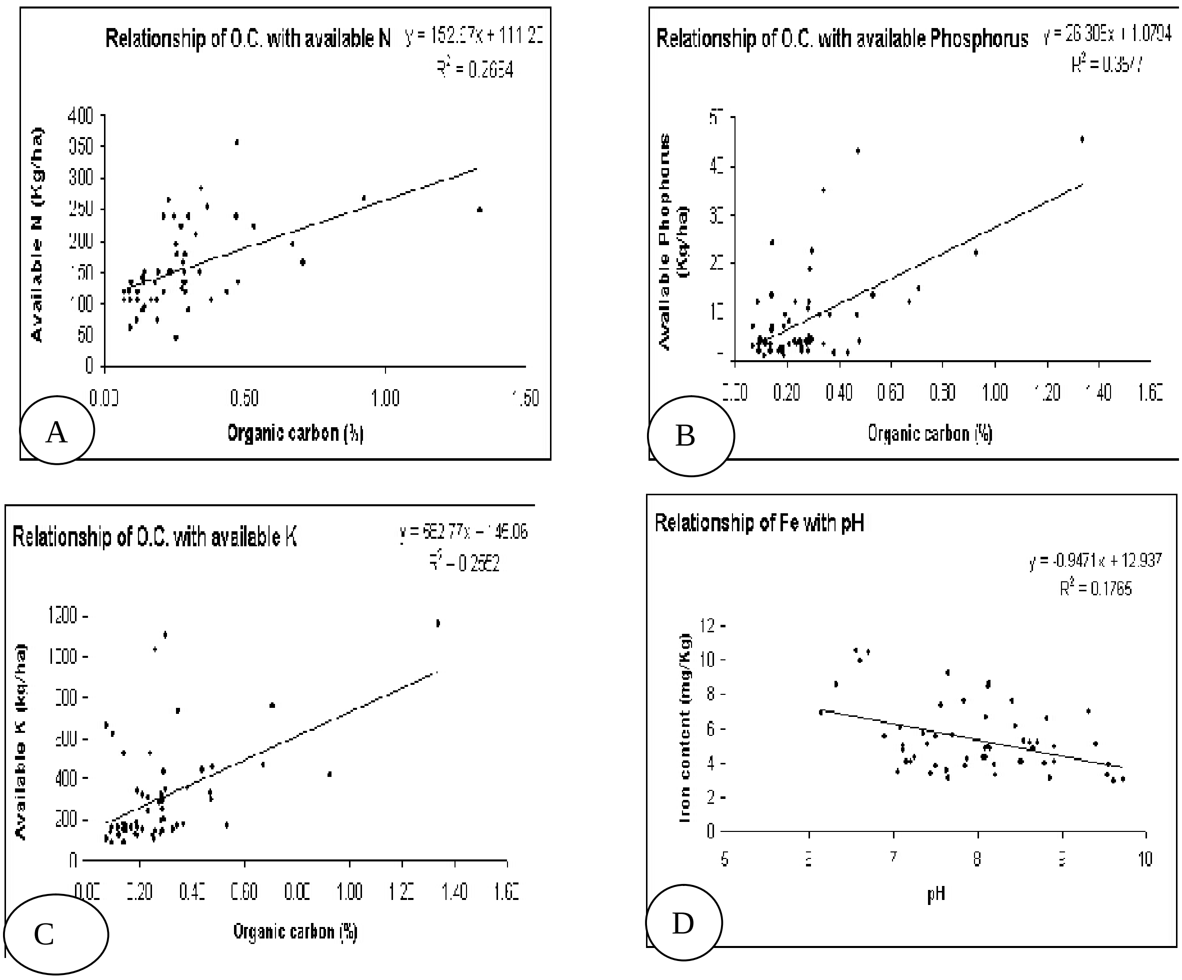


Fig. 1: Location map of study area



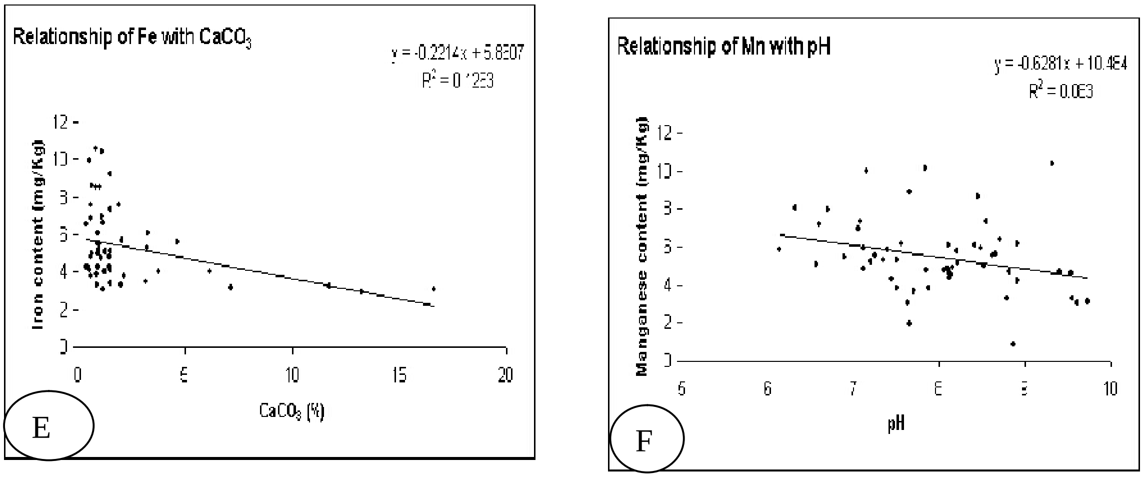
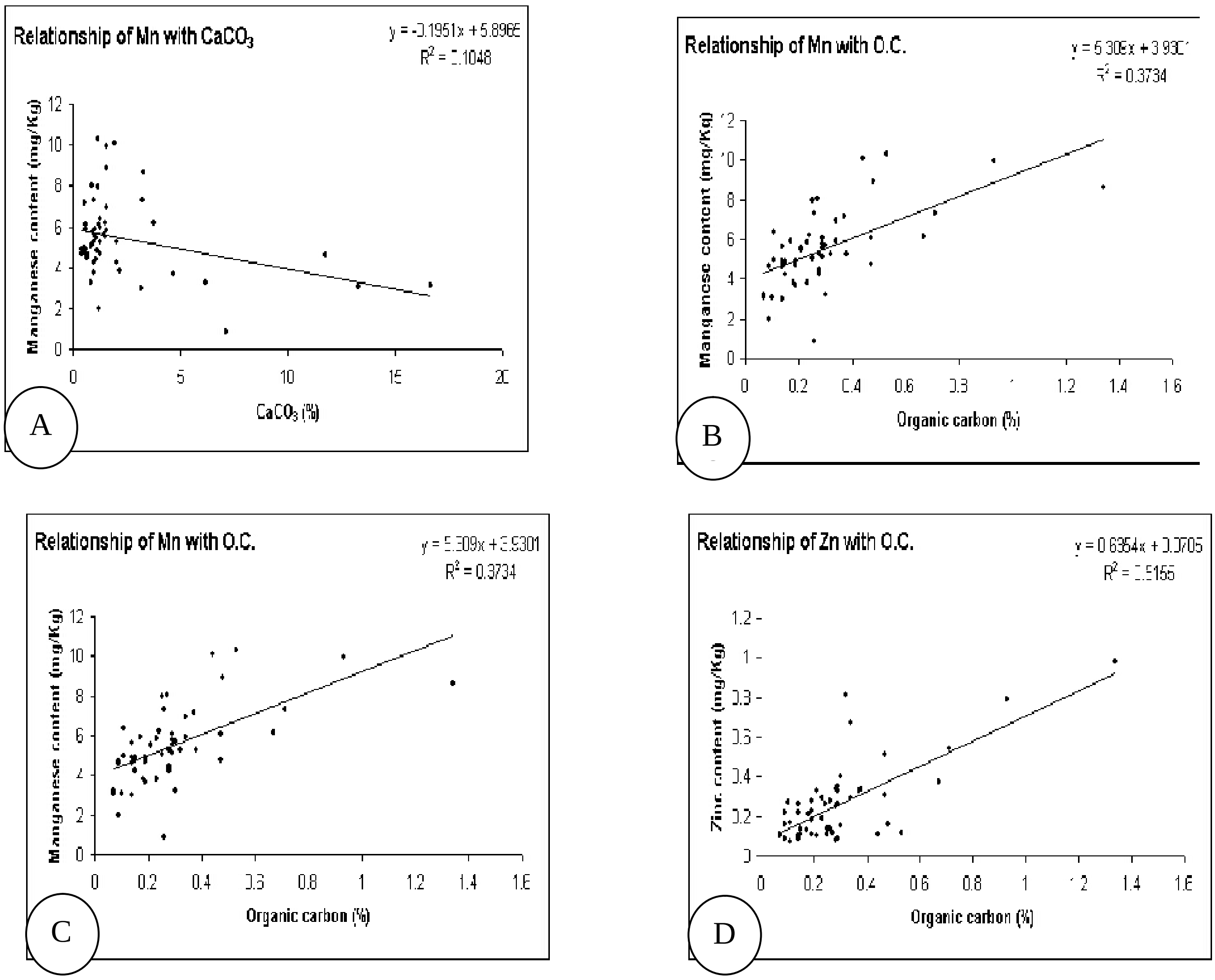


Fig. 2: Relationship of nutrient elements with soil properties (values of all the plains considered together) (significant at 5 % level)



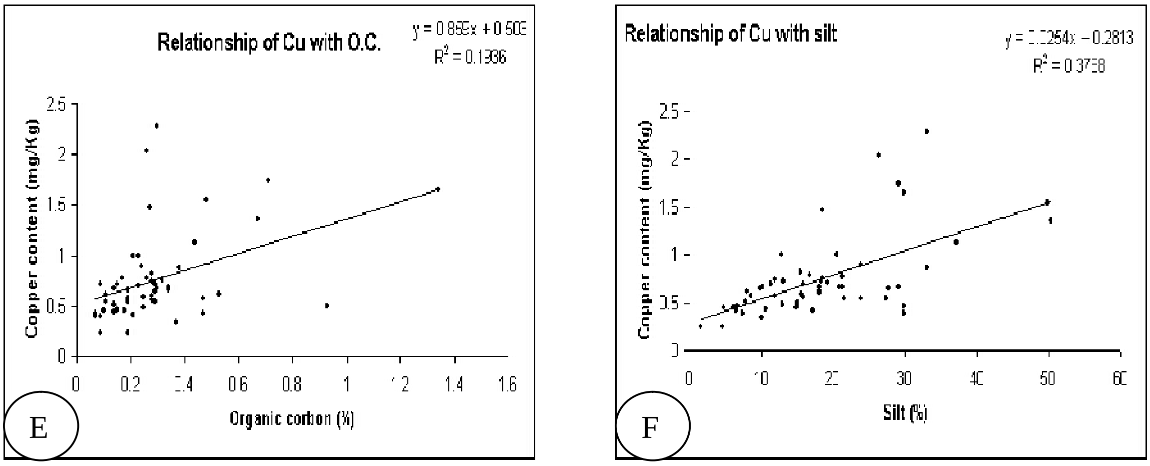


Fig. 3: Relationship of nutrient elements with soil properties (values of all the plains considered together) (significant at 5 % level)

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