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VARIABILITY AND SPATIAL DEPENDENCE OF PHYSICAL AND CHEMICAL PROPERTIES OF SOILS IN FCV TOBACCO FIELDS OF CTRI RESEARCH FARM AT JEELUGUMILLI OF ANDHRA PRADESH

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Studies on variability and spatial dependence of some physical and chemical soil properties in flue-cured tobacco fields conducted at northern light soil farm, CTRI Research Station, Jeelugumilli during 1997-2000 revealed that standard deviation of soil pH was small in relation to the estimated mean. Values of standard deviation of organic C and soil-water retained at different matric suctions were medium while those of EC, Cl, available P and available K were very high in both soil layers. Normal distribution of soil properties over the entire farm was significant at 0.05 level with respect to soil pH in surface layer and available K in sub-surface layer. Some soil properties followed normal distribution in some individual blocks. Values of EC did not follow normal distribution in any block. These results indicated high degree of variability of soil properties within blocks in both soil layers. The parameters were grouped according to the relative amounts of variability. In the lowest class was soil pH with a CV of about 10-11%. On the other hand were four parameters viz., EC, Cl, available P and available K, which were more variable, each with a CV greater than 42%. Variations for soil-water retained at different matric suctions and organic C were intermediate. Spectacular differences in CV values were not obtained between blocks for all soil properties studied except for a few differences in CV values of some properties. Very few numbers of samples are needed to estimate soil pH than the other parameters. Only 5 samples are required to estimate mean within 10% of true mean at 0.05 significance level. Soil-water retained at different matric suctions and organic C require about 31 to 52 samples whereas EC, Cl, available P and available K require 66 to 203 samples to estimate mean within 10% of true mean at 0.05 significance level. Autocorrelation function for different soil properties indicated spatial dependence of soil available P and available K up to 4 m and weak autocorrelation for Cl and organic C.

INTRODUCTION

Soils vary with respect to their properties enormously from site to site even within a limited boundary owing to various factors including soil forming factors like parent materials, topography and vegetation and soil utilization approaches like tillage, fertilization, cropping history etc. Thus, as fields may contain a variety of soil series and topographical features, variability in soil physical and chemical properties within field boundaries is much more common than are homogenous conditions (Cox *et al.*, 2003). Variability can be expressed by its mean and standard deviation, the frequency distribution, fractile diagram and coefficient of variation (Warrick and Nielsen,1980; Baruah and Patgiri, 1996). A requirement common to many field studies is to obtain an average value of different soil properties of the field. The number of samples required to represent a soil property with a degree of permissible error under a given confidence limit would depend on the variability of the property i.e., the estimate of standard deviation (Cline, 1944; Petersen and Calvin, 1965). The number of samples required will be less if the estimate of standard deviation of krigged values is taken instead of estimate of standard deviation of original values (Mc Bratney and Webster, 1983). It is also proved that systematic sampling in grids gives more precise estimates than random sampling as the soil properties are spatial dependent (Mc Bratney and Webster, 1983). The soil at near places tends to be similar in its properties whereas that between two distant places is not and observation therefore carries with it some information from its neighborhood. Spatial dependence of soil properties can be estimated by the autocovariance function, auocorrelation function and semivariogram function (Warrick and Nielsen,1980; Baruah and Patgiri, 1996). An attempt has been made in this direction to describe the variability of some soil physical and chemical properties, to determine the number of soil samples required for estimating soil properties with required precision and confidence limits and to determine the spatial dependence of soil properties in northern light soils farm, CTRI Research Station, Jeelugumilli which may serve as a basis for site specific soil management practices.

MATERIALS AND METHODS

Northern light soil (NLS) farm located at CTRI Research Station, Jeelugumilli, West Godavari district, Andhra Pradesh was chosen for studies on variability and spatial dependence of some physical and chemical soil properties in flue-cured tobacco fields. A total of 292 soil samples were collected from two soil layers (0-22.5 and 22.5-45.0 cm) at 146 locations from NLS farm at a grid interval of 30 m in both directions during 1997-98. Layout of the farm showing the field numbers and sampling sites is depicted in Fig. 1. Soil samples were also collected from two layers at 101 locations in a transect of 50 m in field No. 6A at an interval of 0.5 m, separately, for spatial structure. All the samples were analysed for pH, EC and chlorides as per the procedures described by Jackson (1967); organic carbon and available K according to the procedures described by Page *et. al.* (1982) and available P (Bray and Kurtz, 1945). Soil-water retained at different matric suctions was estimated with pressure plate extractors (Black, 1965) for surface layer samples only.

Complete data on soil analysis were subjected to mathematical analysis to arrive at the desired objectives. As a first approximation, estimates of mean (μ_E) and standard deviation (σ_E) were made (Mode, 1971). Frequency distribution of values on soil properties was examined and tested for significance of normal distribution (Snedecor and Cochran, 1967). Coefficient of variation was calculated to express variability on a relative basis and also to compare values from one parameter to another (Mode, 1971). Number of samples (N) required for estimating mean within 5%, 10% & 15% of true mean of different soil properties was calculated (Petersen and Calvin, 1965; Warrick and Nielsen, 1980 and Madhumita Das, 2007) according to the formula

$$N = x_\alpha^2 \sigma^2 / d^2$$

where σ = standard deviation,
x_α = normalized deviate at required confidence level
d = % distance from mean multiplied by mean

Data on soil properties in the transect were subjected to autocorrelation. Autocorrelation coefficient (r) was calculated (Warrick and Nielsen, 1980) as

$$r_k = c_k / \sigma_E^2$$

where
σ_E = estimate of standard deviation and
k = index for k intervals (lag k)
c = auto covariance,

$$c_k = \{1/(n-k-1)\} \sum_{i=1}^{n-k} (x_i - \sigma_E)((x_{i+k} - \sigma_E)$$

RESULTS AND DISCUSSION

Estimates of mean with respect to soil properties of samples collected all over the farm at a grid interval of 30 m (Table 1) indicated that soils were medium acid in reaction (mean pH : 5.82) in 0-22.5 cm layer and strongly acid (mean pH : 5.44) in 22.5-45.0 cm layer. Soluble salts were relatively low in both soil layers (mean EC : 0.18 to 0.19 dS/m). Mean values of chloride content varied from 24.25 to 25.79 mg/kg and were well within the safe limits for cultivation of flue-cured tobacco. Mean values of fertility status indicated that soils were low in organic carbon, high in available P and medium in available K status in both layers. Mean values of gravimetric soil-water content at different matric suctions were relatively low due to coarse textured nature of soil. Available water-content of soils was also low at 6.05 % (g/g).

Data on standard deviation (Table 1) indicate the range or scatter of the soil parameters. Large values of standard deviation correspond to samples that are dissimilar and small values to samples that are mostly close to the estimated mean. Standard deviation of soil pH in both layers was small in relation to the estimated mean and hence sample values were close to the estimated mean. Values of standard deviation of organic carbon and soil-water retained at different matric suctions in both soil layers were medium in relation to their estimated mean while those of EC, Cl, available P and available K were very high. Samples were highly dissimilar to the estimated mean with respect to soil EC, Cl, available P and available K in both soil layers.

Mean and standard deviation do not in themselves indicate anything about the type of distribution. A population is more completely defined by its frequency distribution. Given the frequency distribution, the averages, dispersions and the probability that a randomly drawn value will be within specified limits can be determined. The frequency distribution of soil pH in surface layer and available K in sub-surface layer followed normal distribution and both were significant at 0.05 confidence level. Other properties did not follow normal distribution in the entire farm (12.02 ha). Frequency distribution of four soil properties namely EC, Cl, available P and available K in both layers tended to show log normal distribution. Values of mean, median and mode were similar with respect to soil pH in surface layer, whereas they were considerably different for the other properties. As the samples were not following normal distribution over the complete farm, the farm was divided into four blocks: Block 1 comprising field Nos. 1A, 1B, 1C, 2A & 2B (2.63 ha), Block 2 comprising field Nos. 3A, 3B, 3C, 4A & 4B (2.48 ha), Block 3 comprising of field Nos. 5A, 5B, 6A & 6B (2.91 ha) and Block 4 comprising of field Nos. 7A, 7B, 8A & 8B (2.13 ha). Small fields on either border measuring 1.87 ha were not considered in dividing the field into blocks. Soil pH in surface layer was normally distributed in all blocks except Block 2. However, it was normally distributed over the entire farm. Electrical conductivity did not follow normal distribution in any block. Organic carbon followed normal distribution in all blocks except in surface layer of Block 4. The same property did not follow normal distribution over the entire farm probably due to inclusion of small fields on either borders of farm, which had higher variation. Available P and available K followed normal distribution in some blocks. Soil-water retained at different matric suctions followed normal distribution in Blocks 1 and 2, but did not follow in Block 3. All these results indicated wide variation in respect of many soil properties within blocks (Table 2). Normally distributed soil properties may be exceptional rather than rule (Young *et al.,* 1999).

The coefficient of variation (CV) is useful for expressing variability on a relative basis. The CV is dimensionless and will be the same regardless of what units are used for measurements. Furthermore, the values from one parameter to another can be compared. The parameters were grouped according to the relative amounts of

Table 1 : Estimates of mean, standard deviation and CV of soil properties

Property	0- 22.5 cm layer			22.5-45.0 cm layer		
	μ_E	σ_E	CV (%)	μ_E	σ_E	CV (%)
pH	5.82	0.65	11.77	5.44	0.57	10.40
EC (dS/m)	0.18	0.10	57.27	0.19	0.11	59.23
Cl (mg/kg)	24.25	13.27	54.75	25.79	13.01	50.42
OC (%)	0.24	0.08	31.67	0.25	0.09	34.95
Av.P (mg/kg)	27.44	19.51	71.10	11.83	8.59	72.63
Av.K (mg/kg)	82.74	35.55	42.97	90.69	37.66	41.53
SWC at 0.10 bar matric suction (g/g)	9.92	2.80	28.19	ND	ND	ND
SWC at 0.33 bar matric suction (g/g)	7.21	2.13	29.57	ND	ND	ND
SWC at 1.0 bar matric suction (g/g)	5.33	1.62	30.43	ND	ND	ND
SWC at 15.0 bar matric suction (g/g)	3.87	1.43	36.94	ND	ND	ND

ND: Not determined

variability. In the lowest class was soil pH with a CV of about 10-11% (Table 1). Low CV values imply that relatively few samples give a good estimate of the mean value. The measured scatter is a combination of the inherent variation and the measuring process. The low CV also was due to relatively precise measuring process. Low CV values of 9.5% (Agbu and Olsen, 1990) and of 10-12% (Cox *et al.*, 2003) were reported for pH. On the other, end of spectrum were the four parameters (EC, Cl, available P and available K) which were much more variable, each with a CV greater than 42%. The measurement processes for these properties are not difficult and hence inherent variation would be very high. Coefficient of variation ranging from 27 to 48% for available P, 22 to 85% for available K and 28 to 65% for clay content was reported in Michigan soils (Cox *et al.*, 2003) and 74.4 to 76% CV for sand content in Illinois soils (Agbu and Olsen, 1990). A coefficient of variation of 250% was reported for electrical conductivity of 1:1 extract and 130% for saturation extract (Wagenet and Jurinak, 1978) of 7.5-15.0 cm depth within 777 km^2 area in Utah. Such a high degree of variation in EC could be attributed to weak spatial dependence and to the large area covered. Variations for the soil-water retained at different matric suctions and organic carbon were intermediate. The CV values for soil-water retained at different suctions ranged from 28 to 37%. Values of CV ranging from 20 to 40% were reported for soil-water retained at 0.1 bar matric suction (Gumaa, 1978), 17 to 24% for soil-water retained at 0.2 bar (Nielsen *et al.*, 1973), 17% for soil-water retained at 0.33 bar (Vaculin *et al.*, 1983), 12% for soil-water retained at 2.2 bar (Cameron, 1978) and 13 to 51% for soil-water retained at 15 bar (Cassel and Bauer, 1975 and Gumaa, 1978). The range in CV for soil-water retained at different matric suctions in the present investigation was of the same order reported by earlier workers as given above. Values of mineralization potential were found to be distributed normally with a CV value of 15% (Mahmoudajafari *et al.*, 1997). Moderate variability of organic carbon was reported by Agbu and Olsen (1990) with a CV of 15% in Illinois Mollisols and with a CV of 12% in North Dakota soils by Kravchenko (2003). However, in the present investigation, CV values ranged from 32 to 35% for organic C which may be attributed to the light textured nature and slope of experimental area.

An attempt was made to examine the variation in different blocks of some soil properties, which had medium to high CV values over the entire farm. Estimates of mean, SD and CV in surface layer of different blocks for soil Cl, available P and soil-water retained at 0.1 and 15.0

Table 2 : Normal distribution of soil properties significant at 0.05 significance level

Blocks	Soil depth(cm)	Soil Property									
		pH	EC	Cl	OC	Av.P	Av.K	SWC at 0.1 bar	SWC at 0.33 bar	SWC at 1.0 bar	SWC at 15.0 bar
Block 1	0-22.5	Y	N	Y	Y	N	Y	Y	Y	Y	Y
	22.5-45.0	N	N	N	Y	N	Y	ND	ND	ND	ND
Block 2	0-22.5	Y	N	N	Y	Y	N	Y	Y	Y	Y
	22.5-45.0	N	N	Y	Y	N	N	ND	ND	ND	ND
Block 3	0-22.5	N	N	N	Y	Y	Y	N	N	N	N
	22.5-45.0	N	N	N	Y	N	Y	ND	ND	ND	ND
Block 4	0-22.5	Y	N	N	N	Y	Y	N	Y	Y	Y
	22.5-45.0	Y	N	N	Y	Y	N	ND	ND	ND	ND
All fields	0-22.5	Y	N	N	N	N	N	N	N	N	N
	22.5-45.0	N	N	N	N	N	Y	ND	ND	ND	ND

Y = Significant; N = Not significant; ND= Not determined bar matric suction are presented in Table 3. The results showed that Block 4 had relatively lower variation that the other three blocks with respect to chloride content and available P status. Block 3 had high variability than other blocks with respect to soil-water retained at 0.1 bar and 15.0 bar matric suction. Block 2 & Block 3 had high CVs than Block 1 & Block 4 with respect to chloride content. Except for these few differences, no spectacular differences in CV values were obtained between blocks. Analyses of spatial distribution of soil properties showed steep gradients of total P, Ca and Mg while C and N did not show steep gradient (Newman *et al.,* 1997). All the soil properties especially soil fertility status, exert profound influence on plant growth. High variation in soil fertility status leads to high variation of yields. Higher CV values for yield parameters obtained in many field experiments in NLS farm could be attributed to high variability of soil properties at block-level. Statistical analyses that are sensitive to non-normal distributions may produce erroneous conclusions when applied to non-normal data.

After discussing the variability of soil properties, it is attempted to the number of samples to the accuracy of estimating the mean. The assumptions that the samples are independent and the number of samples is large enough that the central limit theorem applies were valid since the sampling locations were randomly selected and the number of samples was more than 20. Number of samples (N) required for estimating mean within 5%, 10% & 15% of true mean of different soil properties at 0.05 and 0.10 significance levels are given in Table 4. Value of N for soil pH was 5 to estimate mean within 10% of true mean at 0.05 significance level. Obviously, the central limit theorem does not apply for a sample size of 5. Nevertheless, fewer samples are needed to estimate soil pH than the other parameters. Soil-water retained at different matric suctions and organic carbon require about 31 to 52 samples to estimate mean within 10% of true mean at 0.05 significance level while EC, Cl, available P and available K require 66 to 203 samples. High number of samples required for EC, Cl, available P and available K resulted from higher variability of these properties. Relatively small number of samples was required at 0.10 significance level and for greater distances from true mean. An attempt was made to calculate N for different properties for different blocks and the data are presented in Table 5. It can be clearly seen that the number of samples required for

Table 3 : Estimates of mean and standard deviation and coefficient of variation in surface layers of different blocks for some soil properties

Soil property	Blocks	μ_E	σ_E	CV (%)
Soil-water content (% g/g) retained at 0.1 bar matric suction	Block 1	11.22	3.01	26.81
	Block 2	9.36	2.27	24.23
	Block 3	9.66	2.82	29.23
	Block 4	10.06	2.32	23.04
Soil-water content (% g/g) retained at 15.0 bar matric suction	Block 1	4.48	1.41	31.51
	Block 2	3.54	1.12	31.51
	Block 3	3.92	1.43	36.40
	Block 4	3.93	1.25	31.81
Cl (mg/kg)	Block 1	24.41	10.78	44.18
	Block 2	24.89	16.24	65.23
	Block 3	27.00	16.14	59.78
	Block 4	20.69	6.60	31.88
Av. P (mg/kg)	Block 1	28.82	18.14	62.93
	Block 2	41.94	26.55	63.31
	Block 3	23.61	15.30	64.82
	Block 4	25.83	14.09	54.53

estimating EC, Cl, soil-water retained at 0.1 and 15.0 bar were lowest in Block 4. Values of N were higher in Block 3 with respect to available P and soil-water retained at 0.1 and 15.0 bar obviously due to higher variability in Block 3.

Plot of soil properties in surface layer in a transect of 50 m at a distance of 0.5 m indicated that the values of soil properties were approximately of the same magnitude when measurements were made at shorter distances than at longer distances except for a few aberrations. To examine the effects quantitatively, autocovariance and autocorrelation functions were calculated for different lags. Plot of autocorrelation as a function of lag position for different soil properties are presented in Figs. 2 to 7. Similar plots were obtained for soil properties

Table 4 : Number of samples (N) required for estimating mean within 5%, 10% & 15 % distance (d) of true mean of different soil chemical properties at 0.05 and 0.10 significance level

Property	Soil layer	N at 0.05 significance level			N at 0.10 significance level		
		d=5%	d=10%	d=15%	d=5%	d=10%	d=15%
pH	0-22.5 cm 22.5-45.0cm	1917	54	22	1412	33	21
EC	0-22.5 cm 22.5-45.0cm	504537	126135	5660	355378	8995	3942
Cl	0-22.5 cm 22.5-45.0cm	461391	11598	5143	324275	8169	3631
OC	0-22.5 cm 22.5-45.0cm	154188	3847	1721	108132	2733	1215
Av. P	0-22.5 cm 22.5-45.0cm	777811	194203	8690	547571	137143	6163
Av. K	0-22.5 cm 22.5-45.0cm	284269	7166	3229	200187	5047	2221
SWC at 0.1 bar	0-22.5 cm	122	31	14	86	22	10
SWC at 0.33 bar	0-22.5 cm	134	34	15	95	24	11
SWC at 1.0 bar	0-22.5 cm	142	36	16	100	25	11
SWC at 15.0 bar	0-22.5 cm	210	52	23	148	37	16

Table 5 : Number of samples (N) required for estimating mean within 5%, 10% & 15% of true mean of some soil properties (0-22.5 cm) at 0.05 and 0.10 significance level in different blocks

Soil property	Blocks	N at 0.05 significance level			N at 0.10 significance level		
		d=5%	d=10%	d=15%	d=5%	d=10%	d=15%
SWC at 0.1 bar matric suction	Block 1	110	28	12	78	19	9
	Block 2	90	23	10	64	16	7
	Block 3	131	33	15	92	23	10
	Block 4	82	20	9	57	14	6
SWC at 15.0 bar matric suction	Block 1	153	38	17	107	27	12
	Block 2	153	38	17	107	27	12
	Block 3	204	51	23	143	36	16
	Block 4	155	39	17	110	27	12
Chlorides	Block 1	300	75	33	211	53	23
	Block 2	654	164	73	461	115	51
	Block 3	549	137	61	387	97	43
	Block 4	156	39	17	110	28	12
Av. P.	Block 1	608	152	68	429	107	48
	Block 2	616	154	68	433	108	48
	Block 3	646	161	72	455	114	51
	Block 4	457	161	51	322	80	36

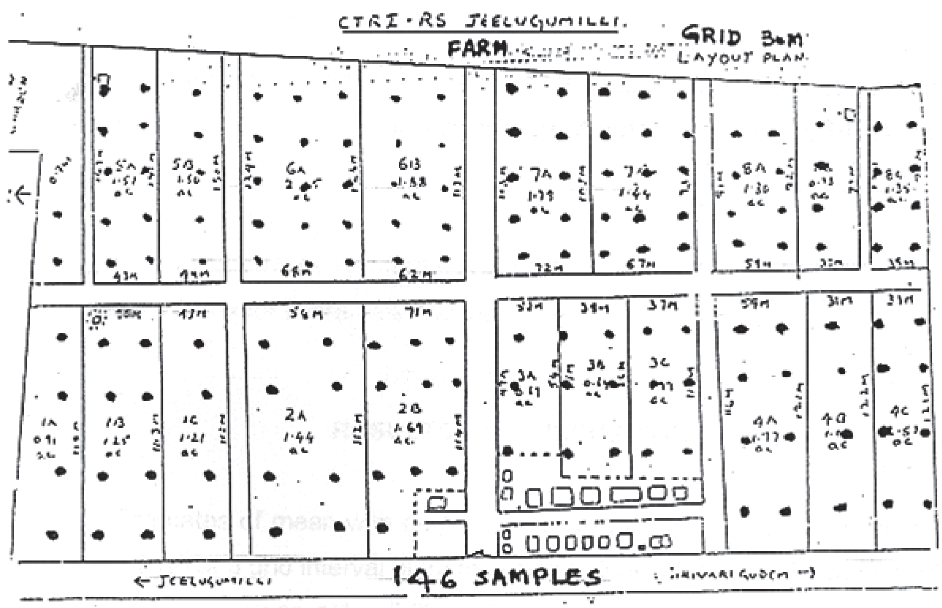

Fig 1.Layout of NLS farm, CTRI RS, Jeelugumilli and soil sampling sites

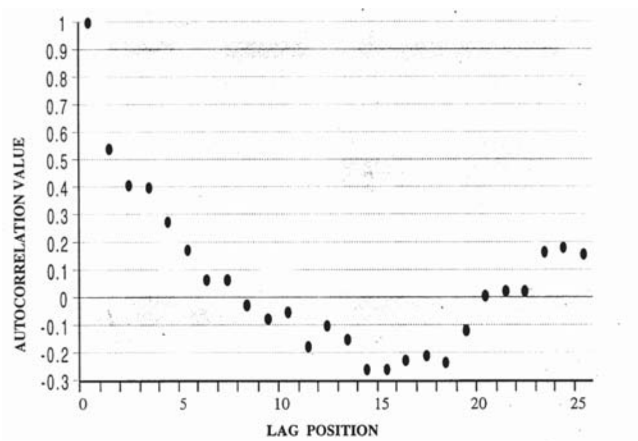

Fig 2. Autocorrelation for soil pH in surface layer

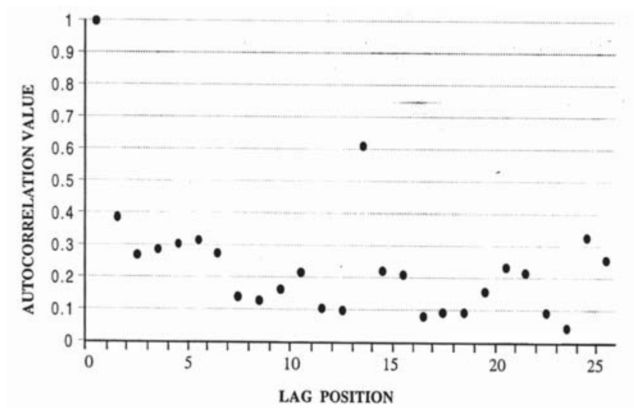

Fig 3. Autocorrelation for electrical conductivity of soil in surface layer

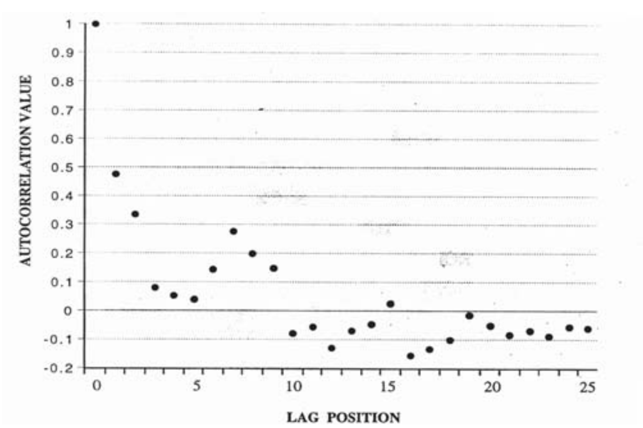

Fig.4. Autocorrelation for soil organic carbon in surface layer

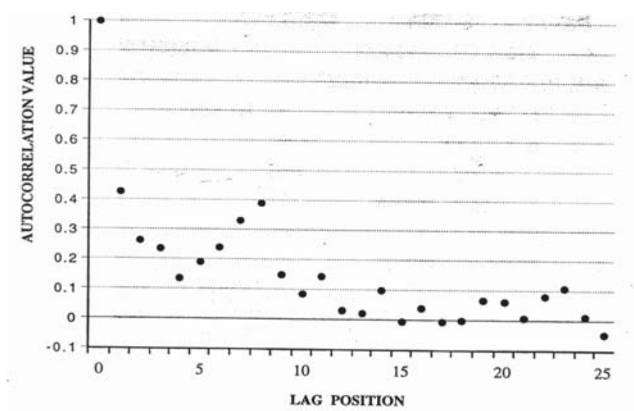

Fig 5. Autocorrelation for soil available potassium in surface layer

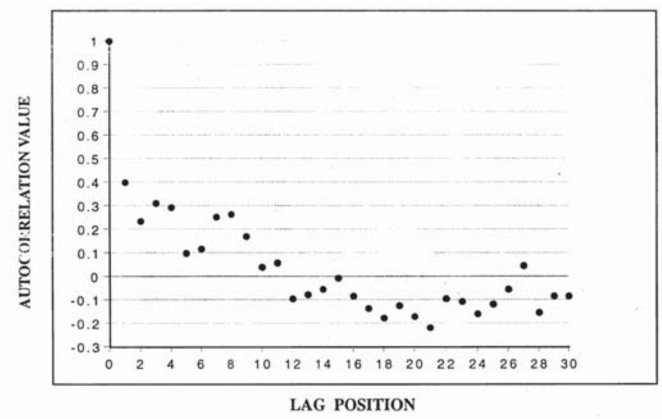

Fig 6. Autocorrelation for soil available phosphorous in surface layer

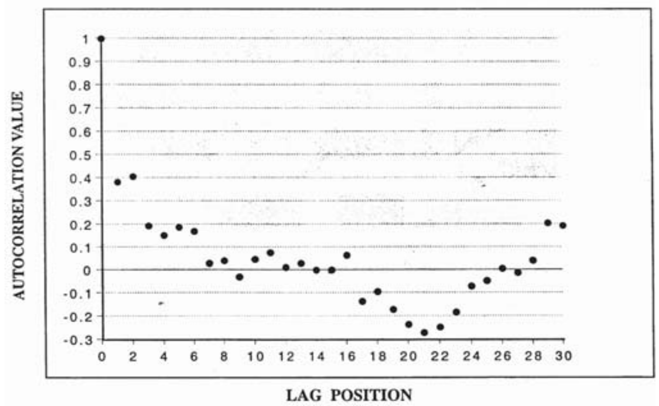

Fig 7. Autocorrelation for soil chlorides in surface layer

of subsurface layer also. The maximum value of autocorrelation is 1 for lag 0 which is trivial but limiting case. Autocorrelation values tended to decrease at greater lags for all the soil properties. These plots indicated that the values were correlated over space. Had the samples been independent, the autocorrelation function would have been near zero at all lags. Spatial dependence was more pronounced for available P and available K and weak for Cl and organic C. It was 4 m for available P and available K. Relatively higher special dependence of 7.2 m for available P and no specific pattern for K was reported by Trangmar *et. al.*, 1987. Spatial dependence was 3 m for EC and 2 m for pH. Relatively higher spatial dependence 4.1 m was observed for pH (Trangmar *et al.* (1987) whereas Wagenet and Jurinak (1978) observed weak special dependence of EC. Chlorides and organic C showed 1 m spatial dependence in surface layer. Earlier results of autocorrelation function indicated that nitrogen mineralization potential was found to have weak autocorrelation (Mahmoudajafari *et al.*, 1997) and spatial dependence of organic C was 7.2 m (Trangmar *et al.*, 1987). Available P and EC were found to have very weak autocorrelation in sub-surface layer.

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