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Soil Fertility Mapping and its Validation using Spatial Prediction Techniques

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SUMMARY

Optimum return from the investment on inputs and minimum environmental pollution are the two major issues to be addressed while prescribing soil test based nutrient recommendations. A comprehensive knowledge of the soil resource is of fundamental importance for efficient land use planning. Green revolution by using high-yielding varieties and improved management technology has increased crop production at the cost of productivity of soil and possible risk of soil degradation. Decrease in the soil fertility and imbalanced use of nutrients are important factors responsible for stagnation or decrease in the crop yields over the years. Thus, it should be firmly understood that further increase in food production must be attained by judicious use of soil as a resource. Fertilizer being the costliest input, the scientific approach towards profitable agriculture would imply, use of plant nutrients according to the actual needs of the soil-crop situation. In this study, soil fertility maps were prepared using point estimates at different geographical locations using stratified multistage stratified random sampling. An appropriate kriging method was used for different nutrients using Akaike's information criterion. The prepared soil fertility maps were validated using soil test values estimated in the next two consecutive years after mapping. There was a significant agreement between estimated soil test values obtained through kriging and those determined in the following years by actual sampling.

Keywords: Soil fertility maps, Geographic Information System (GIS), Global Positioning System (GPS), Sampling, Kriging.

INTRODUCTION

A comprehensive knowledge of the basic soil resources is of fundamental importance for efficient land use planning. The Indian subcontinent possesses widely divergent spectra of changing physiography, climate and vegetation and their combined influence, accentuated by the action of water and wind on the weathering of different types of parent materials, has obviously resulted in soils showing appreciable variations in morphological, physical, chemical and biological characteristics. Thus, the soil representing a continuum of diversified genetic processes and being one of the biggest natural heritages of mankind deserves greater consideration than merely as an inert medium for plant growth.

The tremendously growing population in the country is an acute problem that demands maximum possible output of food, fiber and fuel from each unit of cultivated land area per unit time. The soil fertility undergoes change due to cropping, manure and fertilizer applications. Soil test results of one farm need to have scope to be connected with the broader population of all farms in a given area. The ideal situation would be to sample every farm to get soil fertility status of all the farms. But we may not be able to sample each farm in the population, because it is too costly, troublesome and time consuming, especially with the multiple small farm holdings in many developing countries. We, thus, need to generalize results of sample farms to get information of entire area. For the periods between 1975 to 1980, soil fertility maps for Nitrogen (N),

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Phosphorous (P) and Potassium (K) were prepared using soil test data generated by soil testing laboratories that functioned throughout the country (Ghosh and Hasan 1979). Till date there is no major up-gradation in these maps. Singh *et al*. (2004) used point estimates for districts to prepare soil fertility maps of N, P and K for the states of Andhra Pradesh and Maharashtra. Further, they have interlinked fertilizer recommendations for targeted yields with these maps. Remote Sensing (RS), Geographic Information Systems (GIS), and the Agricultural Non-point Source Pollution (AGNPS) model have been used to assess the runoff and sediment yield from various sub-watersheds above Cheney Reservoir in Kansas, USA (Bhuyan *et al*. (2002)). Ray and Dadhwal (2001) used satellite-based RS data and GIS tools for estimating seasonal crop evapotranspiration in Mahi Right Bank Canal (MRBC) command area of Gujarat, India.

The recent technologies like GIS and Global Positioning System (GPS) thus have much to offer for preparing soil fertility maps. Once the soil fertility maps are created, it is possible to transform the information from Soil Test Crop Response models into spatial fertilizer recommendation maps. Such maps provide site-specific recommendation, validation for soil fertility over the following years. The application of fertilizer on the basis of soil test will not only considerably reduce the cost of inputs for fixed targeted yield(s) but also help in the balanced fertilizer application that will lead to better soil health and sustainability of production. The fertilizer doses for targeted yield can be prescribed to the farmers by locating his field/ area on the map with the help of latitude/longitude information.

MATERIAL AND METHODS

Hoshangabad district was selected for fertility mapping as it has the highest consumption of fertilizer among the districts of Madhya Pradesh. The list of villages and related information of the district was obtained from the Census of India (Bhopal). Hoshangabad district comprised of seven tehsils (viz. Bankhedi, Bawai, Hoshangabad, Itarsi, Pipariya, Seonimalwa and Sohagpur). These tehsils were considered as strata. Eight per cent (approx.) villages were selected from each tehsil using Simple Random Sampling Without Replacement (SRSWOR). From each selected village, six farmers [two of each category viz. large (> 3ha), medium (1-3 ha) and small (< 1 ha)] were selected for collecting further information. One field was selected from each selected farmer keeping in view that the selected field falls in the same village. From each selected field, 6 to 8 soil samples were collected using standard procedure. These samples were thoroughly mixed and a portion of this was retained for nutrient estimation. The location of the mid field was recorded using GPS. All the soil samples so collected were then analysed for N, P, K, organic carbon (OC), electrical conductivity (EC) and pH in the central laboratory of IISS, Bhopal. Standard procedures were used for analyzing pH, EC, (Walkley and Black, 1934), available N (Subbaiah and Asija, 1956), P (Olsen *et al*. 1954) and K (Neutral normal ammonium acetate) (Kundsen *et al*. 1992). After scanning of all the toposheets of Hoshangabad district, the district boundary along with tehsils boundaries were digitized for making base map. After assigning the point value (for N, P, K, etc.) to these sample points the kriging was performed.

It has been observed that among different methods of spatial interpolation of soil properties, kriging is an optimal interpolation method (Issak and Srivastava 1989). Kriging is an advanced geostatistical procedure that generates an estimated surface from a scattered set of points with Z-values. The first step in ordinary kriging is to construct a variogram from the scatter point set to be interpolated. The spatial variation is quantified by the semivariogram. The semivariogram is then estimated by the sample semivariogram, which is computed from the input point dataset. The value of the sample semivariogram for a separation distance of h (referred to as the lag) is the average squared difference in Z-value between pairs of input sample points separated by h. The sample semivariogram is calculated from the sample data using the equation:

$$\gamma(h) = \frac{1}{2n}\sum_{i=1}^{n}\{Z(x_i) - Z(x_i + h)\}^2$$

where n is the number of pairs of sample points separated by the distance h and $Z(x_i)$'s are the value of the characteristic under study at i^{th} location (i = 1, 2, 3,..., n).

Ordinary Kriging is represented by the Spherical, Circular, Exponential, Gaussian, and Linear types. With these options, Kriging uses the mathematical function specified with the semivariogram type argument to fit a line or curve to the semivariance data in the semivariogram. The next step is to fit a model to the points (for N, P, K, etc.) forming the empirical semivariogram. Semivariogram modeling is a key step between spatial description and spatial prediction. The main application of kriging is the prediction of attribute values at unsampled locations. The empirical semivariogram provides information on the spatial autocorrelation of datasets. To select the best model, Akaike's (1973) information criterion (AIC) was used. Estimated (AIC) = $n \ln (R) + 2p$, where n = total number of observations, p = number of estimated parameters and R = residual sum of squares of deviations from the fitted for model. The model having the smallest AIC was used of estimation.

DIGITIZATION OF TOPOSHEETS AND GEO-REFERENCING

Digitization of all the toposheets based on district boundary individually was done. After digitization mosaicing of district boundary was completed. The digital map with tehsil boundaries along with sample fields (dots) of Hoshangabad district at the scale 1:50,000 is given in Fig. 1.

VALIDATION OF THE PREPARED MAPS THROUGH POST SOIL SAMPLE ANALYSIS

For the validation of soil fertility maps which were prepared using the samples collected in the summer of 2006, soil sampling was done in two consecutive years viz. 2007 and 2008. In the year 2007, two blocks of Hoshangabad district were selected randomly and seven soil samples were randomly collected across the block from each of the two blocks. In 2008, soil samples were collected from all the blocks. After collecting soil samples, these were analysed for various soil properties in the IISS Central Lab, Bhopal. In this way set of analysed data for these two years was obtained. Similarly, two sets of estimated data were obtained through prepared maps (Fig. 8). Paired t-test was used to test whether the pair of observations (x_i, y_i) (where x_i and y_i are the nutrient values obtained through lab test and predicted values with the help of kriging respectively) corresponded to the same i^{th} sample unit.

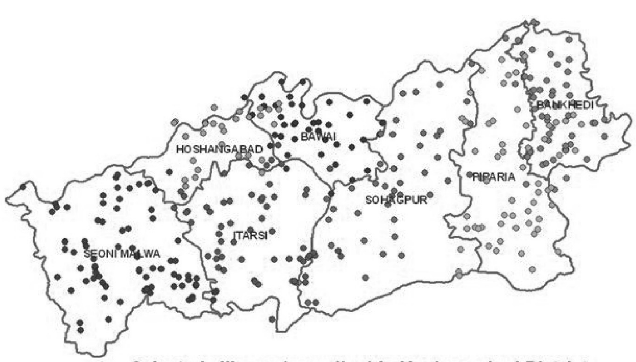

Fig. 1. Selected fields (sampling) in Hoshangabad District

RESULT AND DISCUSSION

Observations Based on Observed Samples

The OC status of the soil was medium (0.50% to 0.75%) in 49.36% area of district, high (>0.75%) in 23.01% and low (<0.50%) in 27.62% area of the district (Fig. 2). Overall OC status of the entire area was medium. Average OC per cent was 0.61%. The status of available N was low (<280 kg/ha) in 91.04% and medium (>280 kg/ha to 560kg /ha) in 9.71% area of the district (Fig. 3). Overall available N status of the entire district was low. Average value of available N was 225.62 kg/ha.

The available P status of the soil was high (> 22.5 kg/ha) in 7.41% area of the district, medium (12.5 to 22.5kg /ha) in 76.98% area and low (<12.5kg/ha) in 15.60% area of the district (Fig. 4). Overall available P status of the entire area was medium. Mean of available phosphorus was 16.72 kg /ha. The available

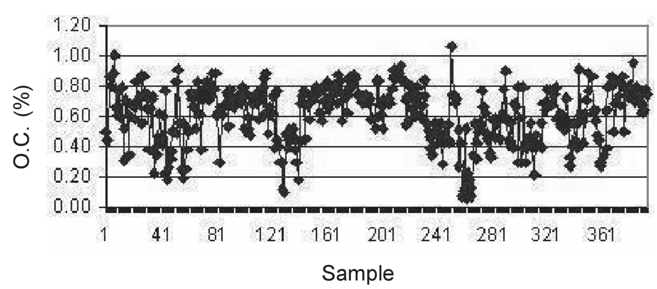

Fig. 2. Distribution of Organic Carbon (%) in Hoshangabad District

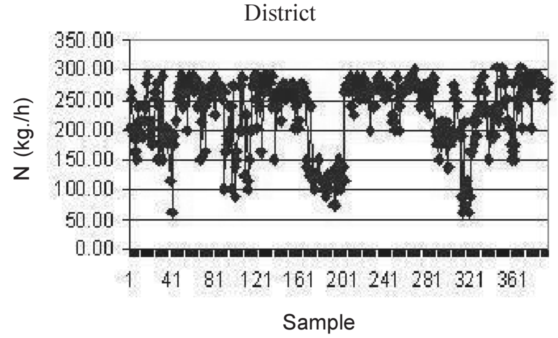

Fig. 3. Distribution of Nitrogen (kg/h) in Hoshangabad District

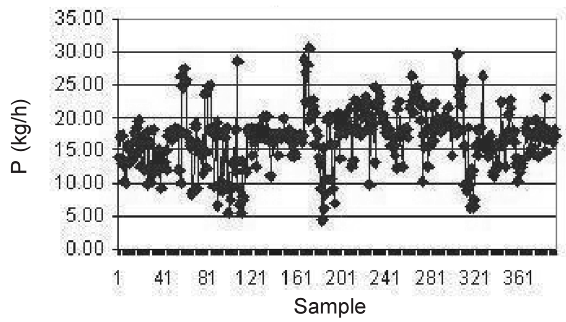

Fig. 4. Distribution of Phosphorua (kg/h) in Hoshangabad District

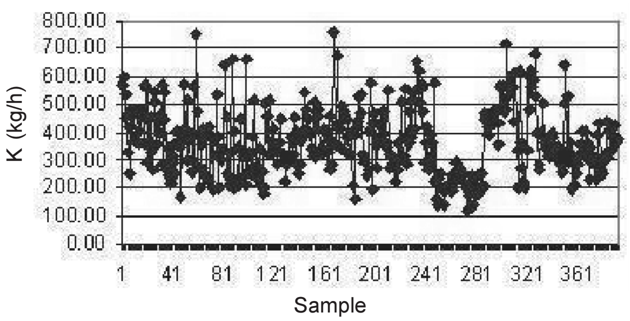

Fig. 5. Distribution of Potassium K (k/h) in Hoshangabad District

K status of the soil was medium (120 to 280 kg/ha) in 24.80% area of district and high (>280 kg/ha)) in 74.93 area of district (Fig. 5). Overall available K status of the entire area was high. Mean value of available K was 367.38 kg/ha.

The EC of soil ranged from 0.057 to 0.717 dS/m (Fig. 6). Mean of EC was 0.223 dS/m. The soils were non-saline. Soils were mainly neutral to slightly alkaline in nature (Fig. 7). Mean value of the pH was 7.60.

GENERATION OF RASTER IMAGE (RESPONSE SURFACE) BY KRIGING

After assigning the point values (N, P, K, OC, EC and pH) to these sample points kriging was performed.

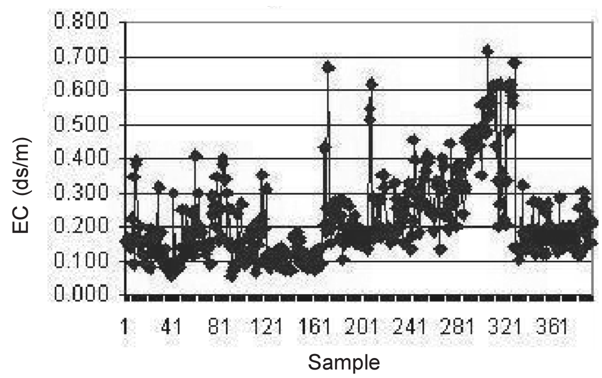

Fig. 6. Distribution of EC (dS/m) in Hoshangabad District

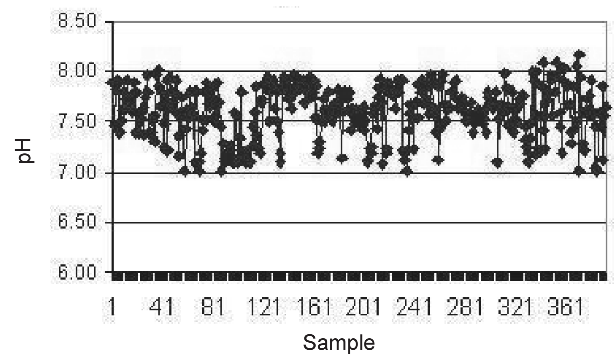

Fig. 7. Distribution of pH in Hoshangabad District

In case of N, spherical method had the least AIC value (Table 1). Hence for N, spherical method was used for kriging. Similarly linear, spherical, exponential, linear and linear Variogram methods of kriging were used for P, K, OC, EC and pH respectively.

Estimated response surface (Fig. 8) clearly showed that in Hoshangabad district OC in soil ranged between 0.28% to 0.81%, available soil N was in the range of 104 to 279 kg/ha, available soil P was in the range of 10 to 22.9 kg/ha, available soil K was in the range of 282 to 529 kg/ha, EC was in the range of 0.08 to 0.34 dS/m and pH was in the range of 7.2 to 7.9. With the

Table 1. Estimated Akaike's information criterion (AIC) for different Variogram models used in kriging.

Kriging Method	N	P	K	OC	EC	pH
Circular	5439.31	1298.91	6041.79	–3645.43	6206.77	–3216.02
Exponential	5440.13	1338.44	6076.24	<u>–3647.29</u>	6211.29	–3210.36
Gaussian	5439.46	1306.40	6050.16	–3645.07	6246.94	–3215.56
Linear	5440.83	<u>1277.16</u>	6168.71	–3645.07	<u>6173.55</u>	<u>–3216.83</u>
Spherical	<u>5438.48</u>	1306.24	<u>6037.63</u>	–3646.18	6226.12	–3215.63

Note : Underlined values are lowest among all the methods.

help of these raster images all the ground points (pixel) were assigned with unique estimated value of respective nutrients. The results indicated that the behavior of the mobile nutrient such as N (and closely associated OC) behaved differently from the non-mobile nutrients such as P & K, as the spatial autocorrelation (equivalently, an increase of semivariance) decreased exponentially (there was no difference in AIC values for N in exponential and spherical models) with increasing distance which was not the case with any of the other soil parameters. It was evident from the Table 1 that the change in other soil parameters except N and OC was slow (non-exponential) with increasing distance.

VALIDATION OF SOIL FERTILITY MAPS

It was observed that calculated Absolute (t) was less that of tabulated t (for P< 0.05) for all the nutrients in 2007 (Table 2). This showed that in the subsequent year there was no significant change in these nutrients. The results of year 2008 showed that only pH changed. For other nutrients there was no significant difference.

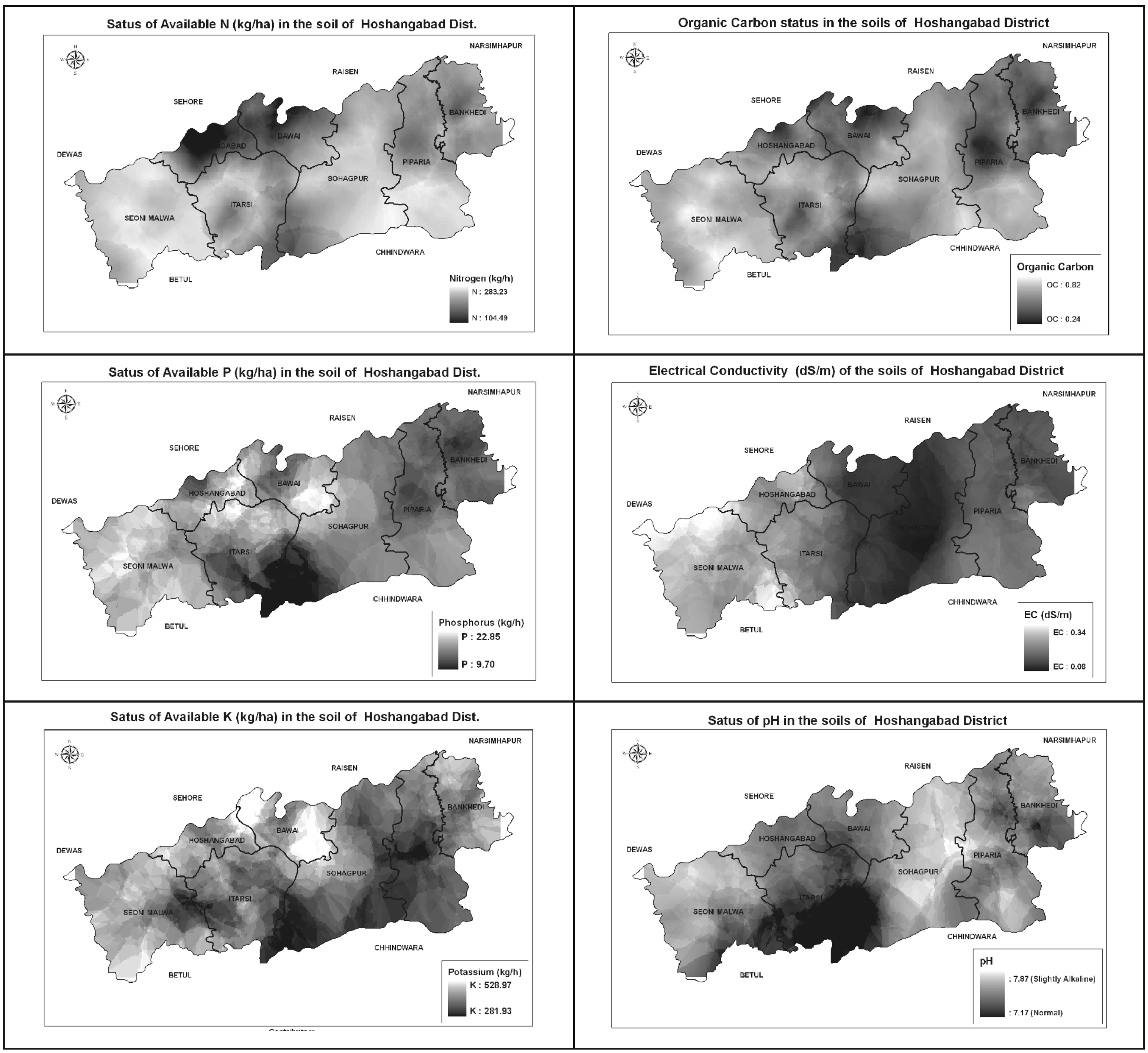

Fig. 8. Kriged raster images (response surface) of different soil nutrients of Hoshangabad district

Table 2. Comparison of actual nutrient analyzed and its value through prepared maps (response surface).

	Year 2007					
	N (kg/ha)	P (kg/ha)	K(kg/ha)	OC	EC (dS/m)	pH
Mean (analysed)	161.75	17.18	433.45	0.60	203.90	7.53
Mean (estimated)	154.68	17.72	429.72	0.57	197.10	7.60
d.f.	13	13	13	13	13	13
t Stat	1.98	–1.38	0.34	1.00	1.34	–1.21
t (critical two-tail) for P<0.05	2.16	2.16	2.16	2.16	2.16	2.16
	Year 2008					
	N (kg/ha)	P (kg/ha)	K(kg/ha)	OC	EC (dS/m)	pH
Mean (analysed)	222.02	16.88	388.13	0.62	176.01	7.53
Mean (estimated)	218.38	16.64	390.95	0.61	173.91	7.62
d.f.	85	85	85	85	85	85
t Stat	–1.48	–1.46	0.80	–1.23	–0.98	4.12
t (critical two-tail) for P<0.05	1.99	1.99	1.99	1.99	1.99	1.99

Therefore, it is inferred that observed soil parameters for Hoshangabad district did not change significantly for at least two consecutive years except for pH.

CONCLUSION

On the basis of above results, it is inferred that the soils in Hoshangabad district are mainly non–saline in nature. The organic carbon status in the soil is medium. The soils are low in electrical conductivity and available nitrogen (N), medium to high in available phosphorus (P) and high in potassium (K). Further, it is clear from the results that a uniform kriging method cannot be recommended for all the soil parameters. It depends on the nature of the soil property. The behavior of the mobile nutrient such as N (and closely associated OC) behaved differently from the non-mobile nutrients such as P and K. This was due to spatial autocorrelation (equivalently, an increase of semivariance) that decreased exponentially with increasing distance and was not the case with any of the other soil parameters. The changes in other soil parameters except N was slow (non-exponential) with increasing distance. Results using paired t-test suggest that once the soil fertility map is prepared it may not change for at least the next two years in Hoshangabad district. Thus, one can use soil fertility maps prepared for Hoshangabad district to obtain soil test values of any field using these maps. These soil test values can further be utilized for prescribing fertilizer doses for optimum production in order to maintain soil fertility.

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REFERENCES

Akaike, H. (1973). Information theory as an extension of the maximum likelihood principle. In 2nd International Symposium on Information Theory (B.N. Petrov and F. Csaksi, editors), Akademiai Kiado, Budapest, Hungary, pp. 267-281.

Bhuyan, S.J., Marzen, L.J., Koelliker, J.K., Harrington, J.A. Jr., Barnes, P.L., (2002). Assessment of runoff and sediment yield using remote sensing, GIS, and AGNPS. *J. Soil Conserv. Ankeny*, **57(6)**, 351-364.

Ghosh, A.B. and Hasan, R. (1979). *Bull. Indian Soc. Soil Sci*., **12**, 1-8.

Issak, E.H. and Srivastava, R.M. (1989). *An Introduction to Applied Geostatistics.* Oxford Univ. Press, New York, 561.

Kundsen, D., Peterson, G.A. and Pratt, P.F. (1982). Chemical and microbial properties. In: *Methods of Soil Analysis*, 225-246.

Olsen, S.R., Cole, C.V., Watanave, F.S. and Dean, L.A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *Circ. US Dep. Agric*., 939.

Ray, S.S., Dadhwal, V.K. (2001). Estimation of crop evapotranspiration of irrigation command area using remote sensing and GIS. *Agril. Water Manage*., **49(3)**, 239-249.

Singh, K.N., Raju, N.S., Subba Rao A., Srivastava Sanjay and Maji, A.K. (2004). GIS based system for prescribing optimum dose of nutrients for targeted yield through soil fertility maps in Andhra Pradesh (AP). *Proceedings of National Workshop on Recent Trends in Earth Resources Mapping, MANIT*, Bhopal, 67-72.

Singh, K.N., Raju, N.S., Subba Rao A., Srivastava Sanjay and Maji A.K. (2004). GIS based system for prescribing optimum dose of nutrients for targeted yield through soil fertility maps in Maharashtra. *Proceedings of National Seminar on Information and Communication Technology for Agriculture and Rural Development NAARM*, Hyderabad, 167-174.

Subbaiah, B.V. and Asija, G.L. (1956). A rapid procedure for determination of available nitrogen in soil. *Curr. Sci*., **25**, 259-260.

Walkley, A.J. and Black, I.A. (1934). Estimation of soil organic carbon by the chromic acid titration methods. *Soil Sci*., **37**, 29-38.