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Distribution Patterns for Available Soil Nutrients and A New Unified Approach to the Study of Soil Properties

By

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ABSTRACT

Soil test distribution patterns were examined statistically for a large sample. Available N and K were normally distributed, while available P distribution followed the semilog type. Conformity to theoretical distributions was very close in all three cases. The identification of these patterns has been suggested as a useful preliminary to quantitative evaluation of available nutrient status of soils for NPK, leading to accurate assessment of fertiliser requirements. It can also be employed for evaluating monetary benefits to be expected by following recommendations based on soil tests. It is suggested that the voluminous soil test data accumulated so far be examined with computers, for the basic distribution patterns mentioned above. There are indications that a number of other soil properties may also be normally distributed.

INTRODUCTION

Ever since soil testing was inaugurated as a regular programme several thousand soil samples have been tested throughout the country and also the world. The number of soils tested so far has reached very high figures, running into several million, as the number of Soil Testing Laboratories all over the country and the world has increased very rapidly in recent times. For Tamil Nadu alone the figure is 2.15 million up to March, 1974. When pieces of information as large in number as soil test values are collected, attempts are usually made to reduce them to a form in which it will be possible to grasp their significance. Otherwise they remain merely as a bewildering collection of voluminous data.

In the case of soil tests three main attempts in this direction appear to have been made. (1) Calculation of percentage of soil samples coming under different arbitrary levels, such as Very low, Low, Medium, High and Very high, this information being presented under arbitrary land demarcations, such as villages, blocks, taluks, districts, and states. Fertility grouping codes like LMH for NPK, incorporating all possible combinations of Low (L), Medium (M) and High (H) levels for N, P and K have also been used for grouping different land units such as blocks. These are commonly known as soil test summaries. Fitts and Nelson (1953) have also attempted presentation of these summaries in the form of two-way tables, indicating combinations of any two nutrient

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elements. Such tables have been found to be useful in deciding the most suitable fertiliser grade for a given situation. (2) Presentation of soil test summaries in the form of maps suitably coloured or hachured to indicate the levels mentioned above. Small circles, divided concentrically into three portions assigned to available N, P and K and colours depicting levels of these nutrients, have also been employed in maps to indicate several possible combinations of the levels of the three nutrient elements. (3) Summation of the above for a given region has been attempted by Parker et *al.* (1951), who have worked out indices for N, P and K based on arbitrary scores (1, 2 and 3) assigned to the levels, low, medium and high, multiplying them by the percentages of each class of values to the total, taking the mean and dividing by 100. A more generalised index, known as the nutrient index has also been suggested, this index being the mean of the ones obtained individually for available N, P and K.

Although the above approaches simplify the process of grasping the information conveyed by a mass of soil test data, they suffer from obvious disadvantages. In the case of soil test summaries the spatial distribution of different patterns of available NPK is not brought out clearly. In maps several approximations have necessarily to be made, boundaries are often arbitrary, and small pockets of dissimilar nature cannot be shown clearly. Nutrient indices are based upon arbitrary scores, and at best, can only give a very rough picture of the nutrient status; critically low values of a particular nutrient, which may render a group of soils unfit for cultivation are not brought out clearly in the final index, and tend to be glossed over, if the other nutrient indices are high.

MATERIALS AND METHODS

In dealing with a large collection of data, statistical approaches are usually fruitful and quantitative. Hence an attempt was made to study basic patterns of distribution of available NPK in a large sample (about 850 to 980). The data were obtained from the huge collection of data on soil tests performed at the Soil Testing Laboratory, Kovilpatti, Tamil Nadu. The soils represent mostly red soils, originating from granites and gneisses, and Tambraparani river alluvium, but include some black, coastal alluvial and lateritic soils also. The rough percentages of the soils under various soil groups are as follows: Red 40; Tambraparani river alluvium: 34; Black and Red; 7; Black: 2; Coastal alluvium: 9; Lateritic: 8. The available soil test values had been obtained through the following methods: N: alkaline permanganate method; P: Olsen's method; K: Flame photometry. Frequency distribution tables were prepared for the various class intervals for soil test values and the frequency plotted against class means, to obtain a preliminary idea of the form of the frequency distribution curve. In the case of available N and K the form of the curve was closely similar to the normal distribution curves which, for these two cases, were fitted with the frequency distribution data, employing the method given by C. H. Goulden

(1962). In the case of available P the curve obtained was of the semilog type. Hence *log* frequency was plotted against class interval mean in each case, when a straight line relationship was obtained. In the case of available N and K, there was a fairly long 'tail' on the right side. This was evidently due to application of fertilisers over a long period of time in a few instances, and hence was omitted from the consideration of the main trend, as not representing the natural condition (Figures 1, 2 and 3).

FIG. 1 FREQUENCY DISTRIBUTION CURVES AVAILABLE NITROGEN

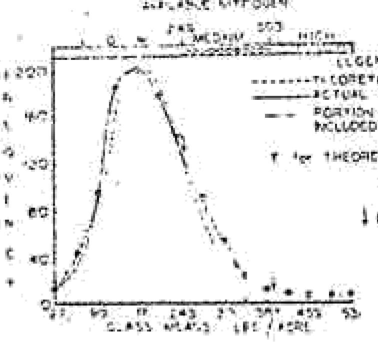


FIG 2 FREQUENCY DISTRIBUTION CURVE AVAILABLE PHOSPHORUS

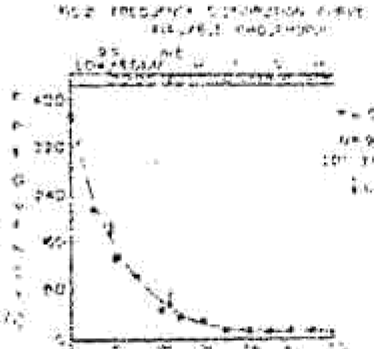
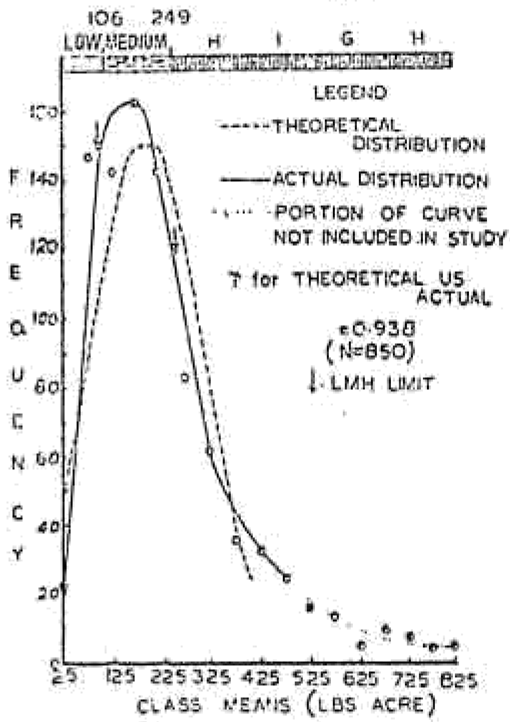


FIG 3 FREQUENCY DISTRIBUTION CURVE AVAILABLE POTASSIUM



RESULTS AND DISCUSSION

Distribution patterns: For available N and K the pattern of distribution conformed closely to the normal distribution. The following normal distribution equation applied to these cases:

$$Y = \frac{N}{s\sqrt{2\pi}} e^{-\frac{1}{2}(x/s)^2}$$

Where Y = Frequency for point x, where x is class value measured from the population mean, N = total number of variates, s = standard deviation of the population, and e is the base of the Napierian system of logarithms. Both x and s are expressed as multiples of the class interval used. The correlation co-efficients for the comparison between theoretical and actual frequencies were very high and very nearly unity (r = 0.948 for available N and 0.938 for available K), indicating the almost absolute conformity of the distribution patterns in these cases to the normal distributions. Mean, standard deviation and CV are given in Table 1. CV for N was appreciably lower than for K. In the case of available P, surprisingly, the normal distribution did not apply, but conformity to the semilog type of relationship was present and was so close; that the correlation coefficient for the relationship between theoretical and actual values was of the very high order of - 0.979, the correlation being negative.

TABLE 1. Mean, standard deviation and coefficient of variation (CV) for soil test values

(Lb / Acre)

Available Nutrients	Mean	Standard deviation	CV Per cent
Nitrogen	182.6	66.9	36.6
Phosphorus	9.45		
Potassium	200.1	107.5	53.7

The actual distribution diagram for available N was displaced slightly to the left of the theoretical one, indicating a very slight positive skewness. In the case of available K, the upper portion of the left limb of the actual distribution curve was displaced slightly upwards and there was also slight positive skewness. In the case of the semilog type of curve for available P conformity to the theoretical curve was very close. Reasons for the particular shapes of the distribution curves for available NPK are hard to find. Normal distribution was found to apply to available N and K, although the origin of these two elements in the soil is quite dissimilar, N being almost completely derived from plant sources, and K from rock minerals. The absence of normal distribution for available P, which is also rock mineral derived, while available K conformed to normal distribution was also surprising. Normal distribution is usually observed for living systems, such as plants and animals, and it was remarkable that this distribution applied to soil available N and K also. It will be useful to investigate the reasons for the conformity of available N and K to normal distribution and of available P to the semilog type of relationship.

An attempt was made to superimpose upon the distribution curves obtained for available N and K, categorisations into Low, Medium and High. This is depicted at the top portions of Figure 1, 2 and 3. The percentage distribution of the total number of samples under the classes, Low, Medium and High is presented in Table 2. In none of the cases did the observed distribution conform exactly to a normal distribution, with the centre in the middle of the Medium range of values. For available P this could be expected, as the distribution itself did not conform to the normal distribution. For available N, although the conformity to normal distribution was close, the mean value (183) was so very much displaced to the left of the midpoint of the Medium range (323) (well under 'Low' category) that about 80 per cent came under 'Low'. For available N only, there was a very rough conformity to the normal distribution (mean = 200) about the middle of the Medium range of values (177). But even here, the number of 'High' value samples was double that for 'Low'. Available N and P, which conformed to different distribution patterns (normal and semilog, respectively) recorded progressive decreases in percentages, starting from 'Low'.

TABLE 2. Distribution of soil test values under various categories

(Percentages of total number of samples)

Available Nutrient levels	Nitrogen	Phosphorus	Potassium
Low	78.9	54.2	17.7
Medium	19.3	32.3	46.9
High	1.8	13.5	35.4

It would be useful to examine the significance of the distribution patterns for available N and K observed above against the background of the Mitscherlich type of response obtained to nutrient elements. In the case of available K, due to the nature of the distribution pattern (normal distribution) roughly symmetrical about the middle of 'Medium' range there is a tendency for a crowding of values at the medium level position. This is also the level which usually produces fairly good response, and hence is desirable. But in the case of available N most of the values are crowded at the left extreme (low level) which would be virtually without use as such, unless adequate fertiliser be applied. The nature of the distribution curves observed in these cases also presupposes that if a uniform fertiliser dose, such as the one recommended by the local agricultural agency (Agricultural Department or University) be applied, very good responses will be obtained in the case of available N, as most of the values cluster around Low; for P however, application of the fertiliser would be expected to produce only moderate response, this being more so for K.

The close conformity to regular patterns such as normal distribution or semilog relationship was surprising in view of the fact that in the above collection of samples, red, river alluvial, black, coastal alluvial and lateritic soils had been included. This simplifies the study, as separate distributions do not have to be worked out for individual soil groups. This has, however, to be verified for black and lateritic soils, as red and alluvial soils have formed the major portion of the collection of soils used for the present study. Obviously this has to be repeated for these soil groups occurring in other parts of the country/world.

The establishment of the exact nature of the distribution patterns for the available plant nutrients is useful from several points of view. First, in the case of available N and K where the normal distribution is found to apply, it enables one to evaluate the benefit expected from the adoption of Soil Test recommendations instead of the generalised recommendations for the region.

If the distribution pattern follows the normal distribution it will be advantageous to have a wide spread of the values about the mean value for the following reasons:- (a) Assuming that the mean coincides more or less with the amount of soil nutrient for which the Departmental recommendation is intended, with soil test values below the mean it will be possible to obtain good crop responses through fertiliser application to raise the level of soil nutrient to the Departmental recommendation; (b) with soil test values above the one for which the Departmental recommendation is intended, it will be possible to decrease considerably the fertiliser to be applied, as the soil itself contains appreciable amounts of nutrients in these cases. The monetary benefit obtainable in this case is not to be judged by the saving realised in the decreased fertiliser bill, but in the amount realisable through actual crop response obtainable by supplying fertiliser that can be purchased with the saving in the fertiliser billmentioned above.

It will thus be seen that a wide spread of the soil test values about the mean will have the greatest advantage from the monetary point of view. It can be shown that this will be the case even if the mean does not coincide with the soil test value for which the Departmental recommendation is intended, as long as the latter lies within the span of soil test values obtained for a given region.

The coefficient of variation (CV) obtained by dividing the standard deviation by the mean is a good measure of the spread of the values about the mean. Hence to obtain the best results through adopting soil test recommendations, it is desirable to have a high CV. It is obvious that if the CV be small and the mean is nearly the same as the soil test value for which the Departmental recommendation was intended, then very little purpose will be served by adopting the soil test recommendation, and the Departmental recommendation will be good enough. In such regions soil testing need not be emphasised and the soil testing staff can be deployed to other regions with high CV's or assigned some other more useful work like soil test-crop response study. Obviously the above considerations will have to be interpreted against the background of crop and varietal differences.

A very important aspect of the determination of the distribution of soil test data is its use in assessing the fertiliser requirement of a given region, knowing the soil groups in the region and the cropping pattern. Estimates of such fertiliser requirements have so far not been made in relation to distribution patterns of soil test values and consequently are not reliable. It is often stated that there is shortage of fertiliser in the country. But as this has not been evaluated in relation to soil available nutrients and their distribution, it is possible that this may not be true, especially for P and K, most of whose soil test values are either high or medium. It is possible that we do not have a real fertiliser shortage, after all, if soil test values for NPK also are taken into account. This kind of realistic computation has not so far been made, but is worth undertaking, if a true picture of the situation is to be obtained. Otherwise most estimates would have the status only of guess work. As the number of data required for this kind of work will be necessarily voluminous, computers can be fruitfully pressed into service.

As the distribution patterns are very regular and conform closely to the theoretical values, it is possible to calculate the nutrient index directly from the equations pertaining to these distribution curves, instead of having recourse to the usual tedious method of calculation. Similarly, the monetary gains expected out of adopting soil test recommendations, instead of the generalised regional one can be worked out mathematically directly from the above equations.

If soil samples are collected systematically from a region so as to conform to the statistical requirements of a sample survey, it is possible to get an accurate idea of the soil nutrient availability situation. Even random samples sent by farmers and extension workers, properly taken, can be quite a close approximation to the ideal sample survey. This has been demonstrated by the results of study on Duplin County, North Carolina, USA (Tisdale and Nelson, 1960) where the soil test summary obtained from farmers' samples gave as good a picture of the general fertility level of the region as the summary obtained from the soil samples collected systematically. Thus the information collected systematically ort hat obtained from the randomsamples can be employed as one representative of the whole region, and the distribution patterns obtained therefrom can be employed for reliable extrapolation to the whole region.

The type of distribution noticed in this study for available nutrients indicates that the soil test values are distributed symmetrically about the mean for available N and K. Generalised fertiliser recommendations for large areas have been fixed, based upon certain assumptions regarding the available nutrient status of the soils in the area. Thus, for Tamil Nadu it has been assumed that available N is low, available P low and available K high. Hence only if the generalised recommendation is followed for the levels stated above can satisfactory yields be obtained. But if it is used below the level for which it was intended, then only less than the maximum possible yield will be obtained. Similarly if it is applied to a soil having more than the assumed fertility level, such fertiliser application will be wasteful as more than the required level would have been applied. But in the case of soil test recommendations the quantity recommended would have been nicely tailored to the exact requirements, such that the maximum yield would be produced in all instances, and there would be no under-or over-fertilisation, as is possible with the generalised fertiliser application.

It would thus be clear that the soil test recommendations would always be successful, but the generalised recommendations would be successful only over a narrow range of soil test values, especially if the Coefficient of Variation (CV) be high. When this is so, it will be misleading to lay out trials comparing STS recommendations with generalised regional recommendations (such as those made by the Agricultural Department) when the outcome is obvious. Unfortunately, several such trials have been laid out in the past with the implied suggestion that generalised recommendations are always inferior to STS ones. It is also surprising that in almost all these cases soil test recommendations have been claimed to be better than the generalised recommendations. Theoretically, according to the soil test distributions observed in this investigation, this will be possible only in about half the number of cases. In about half the cases left the generalised recommendation will actually be in excess of crop requirements.

Krishnamoorthy (1966) has obtained a close correlation between total and available nitrogen (alkaline permanganate method) in a large number of soil samples from South India. Vijayachandran (1966) and Narayanan Nambiar (1973) observed similar high correlations between total and available forms in the cases of P and K respectively in the same region. As the available forms have been established, in the present study, to follow regular distribution patterns, it follows from the above correlations that their corresponding total categories also will follow the same distribution patterns. This type of study can be extended to cover other soil chemical constituents like silica, sesquioxides, divalent and monovalent bases and to available and total forms of essential micro-nutrients.

Narayanan Nambiar (1973) has established close correlations among the various forms (water-soluble, exchangeable, non-exchangeable and mineral forms) of potassium. As available K estimated in Soil Testing Laboratories usually represents the sum of water soluble and exchangeable K, and as this is found in the present study to be normally distributed, it follows that non-exchangeable and mineral forms of K also would be normally distributed. Moreover it is known that CEC and the individual exchangeable cations are closely correlated. This would lead to the interence that the normal distribution would be applicable to CEC also. Venkataramanan (1962) has traced a close relationship between CEC and clay. Durairaj (1961) has established close correlations among mechanical components of South Indian Soils, and has shown how the several mechanical fractions can readily be obtained from clay content, provided that different regression equations are employed for the different soil groups. Raj (1969) has described how a very large number of soil characteristics and constituents can be derived simply from the easily determined parameters, clay content, chroma of soil colour and cation exchange capacity. The considerations set out above would indicate that several soil characteristics are normally distributed.

Unified approach: Combining the distribution pattern approach and the inter-correlations approach, it is possible to derive a highly simplified soil picture for a given region from which representative samples had been taken. Thus the distribution pattern, when established, would take care of the actual variation in soil properties, reducing them to one simple curve, with its own equation; correlation studies would reduce the study of several significant soil characteristics to one of simple derivation from pivotal parameters like clay, chroma of soil colour and CEC, through the application of relevant regression equations, making allowances, if any, for variation in soil groups. Adopting such a procedure, the study of soils in a whole region can be reduced to the derivation and use of a few simple 'master' equations. This approach will be found to be invaluable to organisations such as Soil Survey, which necessarily have to deal with a baffling array of soil parameters which vary from place to place. Soil classification may also be modified and made on the fundamental basis of the pattern of distribution of soil characteristics rather than on arbitrary morphological features, as is being done now. The use of a graph for describing a real variations of soil properties stresses upon the whole range of soil variations in space as a continuum rather than as a discontinuous gathering of material.

In the case of certain soil properties like soil available moisture (Field capacity minus wilting coefficient) the distribution pattern for this parameter will enable one to calculate in a reliable way, the total capacity for moisture storage in the soil for a given region, recording variations for this parameter from place to place. This information will be found to be very useful in taking important decisions on irrigation water. In drylands, this information, taken along with rainfall distribution data, will be invaluable in deciding upon the volume and frequency of supplementary irrigation at critical periods of moisture stress.

One of the significant benefits of identifying available nutrient distribution patterns is the ease with which the total available nutrients in a given area can be calculated rapidly from a simple equation describing the distribution. 'This should be of help to administrators and planners in determining policies of fertiliser production, distribution and consumption'. Soil test summaries, maps and nutrient indices also serve the same purpose, but not to the same degree of accuracy, or ease and rapidity of calculation. Obviously in such calculations, crop patterns and varieties have also to be taken into account.

The study of distribution patterns of soil parameters evidently deals with a very large number of individual pieces of data, often running into millions. The total number of soils tested in all the soil testing laboratories all over the country, which at present runs into several million, and tends to increase in geometric progression over the coming years, is an example of this situation. It will be helpful if central agencies like the Soil Survey and Testing ones take up the task of evolving distribution patterns for important soil characteristics and available nutrients, pressing into their aid, computers, through whose aid only the whole work can be done in a reasonably short time. Raj (1969) has stressed the necessity for omitting a few obviously discordant values in studies of this kind, in order to get a clear picture of the underlying patterns. Such a procedure will have to be adopted, even while working with computers, if the basic patterns are to stand out clearly.

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