Int.J.Curr.Microbiol.App.Sci (2023) *12*(05): 199-217

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 12 Number 5 (2023)**
Journal homepage: http://www.ijcmas.com

Original Research Article https://doi.org/10.20546/ijcmas.2023.1205.026

Comparison of Soil Properties of a Tea Estate using Classical and Geostatistical Technique

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Keywords

Classical statistics, geostatistcs

Article Info

Received:
05 April 2023
Accepted:
06 May 2023
Available Online:
10 May 2023

ABSTRACT

An attempt was made to access soil properties of a tea estate using classical and geostatistical technique where production of tea has decreased tremendously due to an increase in limitation of the soil factors governing production. Similar problem has been reported from many other estates. Tea being a major revenue earner and its productivity being governed by soil factors, this work was undertaken to find out the degree of limitations and possible improvement in production of the crop.

Introduction

Assam is famous for its tea cultivation and production in the world. Tea is one of the most important revenue earner of the state. Upper Brahmaputra Valley Zone of Assam alone takes the pride of possessing about 60 per cent of the total tea estates of the state, it has about 564 tea estates out of the 864 tea estates of the state. Large quantities of available water is necessary for the vegetative growth of tea.

Development of buds takes place in presence of high moisture in the soil. However, excess water is more dangerous than a water deficit for tea. In tea generally two types of water stress are encountered *viz.* drought due to deficit and waterlogging due to excess water. Water deficit leads to wilting which starves the tender leaves and shoots on the plucking table of the tea bush. Waterlogging during the rainy season is a common feature in tea soils. At times plants are also submerged upto the ground level for prolonged duration.

The primary cause of suffering of plants due to waterlogging is due to lack of soil aeration. Paucity of oxygen in the soil leads to suffocation of the roots which retards the absorption of nutrients and synthesis of vital hormones like cytokinin and gibberelic acid.

Ethylene gas is evolved with prolonged waterlogging which suppresses the growth and accelerates leaf fall through abscission. The most affected part of the plant under waterlogged condition are the roots.

Materials and Methods

The state of Assam is situated in the extreme north eastern side of Assam between 24^o and 28^o N latitudes and 89^{o}50' and 96^o E longitudes. The present location is about 30 kms east of Jorhat. The estate has 21 sections with a gross area of 125.38 ha approximately. By and large the area is mainly flat with a little elevation.

A small rivulet is at the southern boundary of the estate, which serves as the main outlet of excess water collected from the garden, but unfortunately this outlet has been blocked by human interference and as a result the water moves out of the estate at a very slow rate to join the main river. The climate of the area is mainly humid sub-tropical and is characterized by hot wet summer and dry cool winter. The mean annual maximum and minimum temperature is 27.87^o C and 19.53^o C respectively. The mean annual rainfall is around 2000 mm.

In the present study random sampling is followed as the area under the present investigation is nonuniform in all the aspects including cropping history of the crop grown. The soil samples are collected in random which are later transferred to grid coordinates. Out of all the sections only sixteen (16) sections are selected for soil sampling, half are from water logged sections and half from non water logged sections. The number of samples collected are from two soil depths *viz*. 0-30 cm and 30-60 cm from 10 locations in each sections.

The sections are as follows:

Waterlogged sections

Section number 1, 2, 3, 4, 5, 6, 7, 8 and 9

Non waterlogged sections

Section number 10, 11, 12, 13, 14, 14A, 15 and 16. Malik *et al.,* (1994) rated water table at a depth of 0.4 to 0.9 m shallow (SWT) and medium water table (MWT) at a depth of 0.8 to 1.3 m.

Water Stable Aggregates

Fifty gram soil was kept in humidity chamber (at 95 % RH) for 24 hours and then transferred to the topmost sieve of the nest of sieves of Yoder apparatus arranged in the order of 2 mm, 1 mm, 0.5 mm, 0.25 mm and 0.15 mm below which a container was fixed. The nest of sieves was then emersed under water, shaken in Yoder Apparatus for 5 minutes. Each of the fractions retained in the sieve was collected and air dried, weighed and per cent aggregates of various size ranges were calculated.

Single value constant of aggregation was then calculated from the equation given by van Bavel (1949) for calculation of mean weight diameter, as follows:

$$\text{Single value constant} = \sum_{i=1}^{n} X_i d_i$$

where, Xi is the proportion by weight of a given size fraction and di is the mean diameter of each size fraction in mm. Thus, the single value constant was expressed in mm.

Index of Soil Water Availability

Suitable quantity of air dry sieved soil (2 mm), packed into rubber rings of 1 cm height and 5 cm diameter, were placed on porous plates (1 bar to 15 bar sensitive ceramic). The plates used for this purpose were then saturated with distilled water with samples thereupon. The samples were then equilibrated at different tensions using pressure plate apparatus (Richards, 1948).

Water contents at 10 kPa, 33 kPa and 100 kPa tensions were determined in 1 bar sensitive ceramic plates and water contents at 500 kPa and 1500 kPa tensions were determined in 15 bar sensitive ceramic plates following the attainment of equilibrium after 24 hrs as confirmed by cessation of out flow from the outlet end of the pressure apparatus. The results obtained were then expressed on volumetric basis.

Indices of soil water availability like available water (AW) and readily available water (RAW) were calculated as follows-

AW = (Water retained at 33 kPa) - (Water retained at 1500 K Pa) (7)

RAW = (Water retained at 10 kPa) - (water retained at 100 kPa) (8)

'b' parameter

The 'b' parameter was calculated with the help of linearised soil water characteristic (h-q) curve from the relationship given by Gardner (1970). It is expressed as

$$h/h_e = (\theta/\theta_s)^{-b}$$

where, h is the soil water tension (k Pa) corresponding to the volumetric water content θ, h_e is the air entry potential and θ_s is the saturation water content.

For the present investigation two types of statistical methods were used to study the variability:

Classical statistical techniques

The classical statistical techniques most commonly used to estimate soil variability are semiquantitative in nature as they do not permit estimation of the rate of change of variation of soil properties with distance. These methods essentially rely on the principle of analysis of variance technique which presume that the observations are random or spatially independent of each other. They are limited to the estimation of the mean variance, standard deviation and coefficient of variation and such other parameters of the observed values. The parameters are used to estimate the future numbers of observations to be taken for the given property, to be recorded in order to secure confidence limit for a range about the mean. They also examine the magnitude and nature of variation of the observations.

The statistical dispersion *e.g.* coefficient of variation, standard deviation, standard error, confidence limits are used to indicate the precision of the mean as an estimator, since the mean values are taken for estimation of a property at an unsampled location with sampling units.

These statistics have been extensively used to document the variation of the soil properties within sampling areas such as mapping units. The various methodologies of classical statistics adopted for the following investigation are discussed as under:

There are three well known measures of the central tendency of a frequency distribution, these are mean, median and mode.

Mean

The mean is the arithmetic average and is the result obtained when the sum of the values of the individuals in the data is divided by the number of individuals in the data.

The mean is usually denoted by the sign μ and is given by:

$$\mu = \Sigma x_i / N \text{, for } i = 1 \text{ to } N$$

It is expected that the value of a soil property 'z' at any location 'x' within a sampling unit will be given by

$$z(x) = m + e(x)$$

where, m is the population mean or expected value of 'z' and e (x) represents a random spatially correlated dispersion of values about the mean. Sokal and Rohalf (1969) observed that the deviation from the population mean is assumed to be normally distributed with a mean of zero and a variance.

Median

The median is the value which is located in the middle of a series when the observations are arranged in order of magnitude and it divides the series into two halves.

**Of these measures of central tendency the arithmetic mean is by far the most important and commonly used. The mode is the most striking measure of the central tendency.

Mode

The mode is that value of the variate which occurs most frequently in a frequency.

Standard deviation

Standard deviation (SD) is a measure of dispersion and is calculated by squaring the deviation of each observations from the mean, adding the squares, dividing by the number of observations and extracting the square root, according to the formula

$$\sigma = \{ d^2 / N \}^{0.5}$$

where σ stands for standard deviation, d is the deviation of the mid value of the class from the population mean, always taken positive.

Coefficient of variation

A measure of variation which is independent of the unit of measurement and is therefore useful for comparison between different populations is provided by the standard deviation expressed as a percentage of the mean. This measure is known as the coefficient of variation and is given by

$$C\,V = [\, \sigma / \mu \,\} \times 100$$

The mean gives an average value of the random variable. The standard deviation (O) signifies the range or scatter of the variable. Large values of S.D correspond to the samples which are dissimilar, whereas small values of SD indicate samples which are close to the mean. They indicate the magnitude of variation and not about the type of distribution of the population.

This parameter has been found most convenient and therefore, most commonly used parameter for the estimation of the elative magnitude of variability. Coefficient of variation is dimensionless and as such its value remains the same regardless of the units of estimation. Low coefficient of variation values estimate a property under study.

Dahiya *et al.*, 1984b, based on the coefficient of variation values reported by different workers grouped various soil properties in three classes according to their consistent relative amount of variability.

Low variation

In the lowest class are those having coefficient of variation value < 15. These properties are normally bulk density, pH, saturation water content and available water capacity.

Medium variation

Those having coefficient of variation values from 15 to 75 are in this class. In fact most soil properties comes under this category *viz.* total P, total N, Ca, Mg, Na, soluble anions, organic carbon, sand, silt, clay, unsaturated soil water content etc.

High variation

Those having coefficient of variation values >75 are in this group. Properties like K, infiltration rate, diffusivity, dispersion coefficient, pore water velocity etc.

Parameters in the high variation class are generally, not normally distributed. Rather they are log-normally distributed. Skewness of distribution will be seen with large coefficient of variation values<50 may be assumed to be normally distributed, but this fact too may not always be true.

To compare the variability between fields, mapping units coefficient of variation can be used with the help of t- test as illustrated by Courtin *et al.*, (1983).

The variance associated with each coefficient of variation values is calculated from the formula given by Sokal and Rohlf (1969).

Geostatistical technique

The data's that are collected are tested for spatial dependence using the selected geostatistical techniques which are described as under

Why geostatistics !!

The variations are said to be randomly distributed within sampling units in classical statistics. That is to say that the observations of a given parameter are statistically independent of one another regardless of their location in the field. Warrick and Nielsen (1980); Dahiya *et al.,* (1984b) concluded that the soil parameters are continuous variable whose values at any location can be expected to vary according to direction and distance of separation from neighboring samples. Such a variation in soil parameters results in their spatial dependence within some localized region. As the classical model assumes random variation and takes no account of spatial correlation and neighborhood dependence of sample locations the classical technique is inadequate. As expressing variability without considering the spatial dependence may not be statistically valid.

There are many techniques which incorporate sample location to varying degree are used for interpolation of soil properties. These includes proximal weighting, moving averages, weighted moving averages using inverse distance and inverse distance squared function and spline interpolation. With the development of geostatistical theory spatial dependence of soil properties are enabled to be directly considered for interpolation. These developments are based on the theory of regionalized variables, which takes into account both the random and structural characteristics of spatially distributed variable to provide quantitative tools for their description and optimal unbiased estimation.

Results and Discussion

Basic soil physical properties

The bulk density of surface soil ranged from 1.61 Mg m^{-3} 1.00 Mg m^{-3} with a mean value of 1.48 Mg m^{-3}. On the other hand the values of bulk density in the subsurface soil ranged from a maximum of 1.8 Mg m^{-3} to a minimum of 1.8 Mg m^{-3} with a mean value of 1.47 Mg m^{-3}. Thus, the bulk density values were nearly equal at both the depths of soil, indicating that there is not much of vertical variation of the property. The coefficient of variation were 5.08 and 4.59 for surface and subsurface soils, respectively, indicating equal magnitude of variability at both the depths. These values of coefficient of variation were almost at par with those reported earlier by Nielsen *et al.,* (1973) and Patgiri (1993). Thus, an universality of variation of bulk density irrespective of soil type or location can be assumed.

In general the soil pH indicated strongly acidic soil reaction in both the soil depths. The pH of the soils ranged from 4.10 to 5.10 in the surface soil and the same ranged from 4.20 to 5.20 in the subsurface layers, with their corresponding mean of 4.56 and 4.64, respectively. The standard deviation were 0.21 and 0.20 and their corresponding variances were 0.0487 and 0.0414, respectively, for the surface and subsurface soil layers. The coefficient of variation values in case of pH too were very small and were 4.60 and 4.31, respectively for surface and subsurface soils. Thus, unlike bulk density pH too had low variation in either vertical or horizontal direction in these soils.

The soil under study are low in organic carbon content for plantation crops like tea, where addition of organic matter in the form of litter from the annual pruning cycle or added organic matter is a common practice. The mean values of organic carbon content at surface soil was 0.57 per cent with a range of 0.31 to 0.81 per cent. Again in subsurface soil the range was 0.41 to 0.96 per cent with a mean value of 0.57. This indicated that organic carbon content at both the soil layers were nearly equal and that there is no migration of organic carbon to the subsurface soil from the surface. The values of all other statistical parameters like standard deviation, variance and coefficient of variation were all the same for both the depths, indicating very good homogeneity of variability at both the depths. This is also an indication that deposition of organic carbon at surface has not been adequately maintained and if this continues for a longer period of time, this may be a cause of concern leading to adverse effect on crop yield. The coefficient of variation values for organic carbon reported by Beckett and Webster (1971); Indorante and Jansen (1981) and Patgiri (1993) are higher than the observed coefficient of variation values. This indicates that the soils under study maintain a homogeneity so far as the organic carbon for both depths are concerned. This can be attributed to the fact that tea is a long duration crop and as there is less soil disturbance within short periods of time.

Aggregation is an important soil parameters that controls a number of soil properties like water transmission and retention. The status of aggregation is indicated by the mean weight diameter, which is a weighted mean of the various size fractions of aggregates in the soil. This property although do not have any direct role, may have tremendous effect on crop performance through its indirect effect. The mean weight diameter of the soils ranged from 0.15 mm to 1.11 mm and 0.10 to 0.60 mm with their corresponding mean values of 0.64 mm and 0.28 mm for the surface and subsurface soil layer, respectively. The mean values indicated that the status of aggregation at subsurface soils is poor as compared to the surface soil. This is likely to have a great impact on soil water transmission properties due to poor structural development in the subsurface soils. Water from the surface layer would be transmitted very easily due to good structural status indicated by the high mean weight diameter. But once the water reaches the subsurface soil, it is likely that a perched water table may develop for a brief period of time. This perched water table coupled with high ground water table of the estate may have added to the lowering of crop performance. The coefficient of variation of mean weight diameter for both the soil layers were 25 per cent and 48.57 per cent, respectively. These values indicated medium range of variability at both the depths, besides indicating that there is likelihood of a vertical variability of mean weight diameter.

Most soil properties are manifestations of the textural makeup of the soils. Texture unlike, soil structural status, have tremendous indirect effect on crops performance through its role in determining the behaviour of many soil properties having direct bearing on crops. Hence, it is imperative to study the behaviour of soil texture in any study involved in interpretation of impact of soil properties on crops. Literature suggest that the distribution of sand, silt and clay have wider variability with respect to soil type, location and depth and is tremendously effected by the soil management practices. Thus, an assessment of the textural make of the soils were also made.

Sand content of the soils ranged from 13.11 to 48.11 per cent in the surface soils and from 12.10 to 49.41 per cent in the subsurface soils. The mean sand content was found to be higher in the surface soil as compared to the surface soil, indicated by the mean values of 26.48 and 25.72 per cent, respectively. Higher values of standard deviation and variance were found in the surface soil as compared to the subsurface soil. However, the coefficient of variation was slightly higher in subsurface soil (38.37) as compared to surface soil. In general the coefficient of variation values were of medium range.

Silt content ranged from a low of 8.77 to a high of 55.12 per cent in the surface soil while the same ranged from a high of 59.23 to a low of 6.71 per cent in the subsurface soil. The subsurface soil showed slightly higher values of all the statistical parameters as compared to the surface soil. Thus, it was observed that the coefficient of variation values obtained for silt content for the both the soil depths were in the medium category (Table 6).

The clay content in the soil ranged from 22.06 to 51.23 per cent in the surface soil while in the subsurface soil the same ranged from 14.1 to 52.79 per cent. Unlike the silt content, the mean and coefficient of variation values obtained for clay content were found t be slightly higher in the subsurface soil. This indicated that the variability of clay in both the layers of soil were nearly equal and that clay content will not show vertical variability. The values of coefficient of variation indicated a low range of variability showing near homogeneity of variation of the clay content at both the soil layers in the soils of the estate.

The coefficient of variation values obtained from the analyses shows that sand happens to be the most variable of all the three soil separates. When coefficient of variation values for both the depths are compared than they are seen to be almost at par for each soil separate. The observed coefficient of variation were found to be higher than those reported by Babalola (1978) and Patgiri (1993).

However, they are almost at par with those reported by Nielsen *et al.,* (1973). The coefficient of variation of silt content are found to be higher than those reported by Babalola (1978); Nielsen *et al.,* (1973), but are found to be at par with those reported by Patgiri (1993). In the case of the clay content the observed coefficient of variation values are lower than those reported by Patgiri (1993) but are observed to be higher than those reported by others (Nielsen *et al.,* 1973).

As such it may be assumed that a homogeneity is maintained by the three soil separates with respect to their distribution pattern. This may be largely attributed to the alluvial origin of the soils (Anlauf *et al.,* 1987; Anlauf, 1988 and Patgiri, 1993.)

Soil water retention properties

The saturated water content of the soils ranged from a high of 0.73 to a low of 0.30 cm^3 cm^{-3} in the surface soil and from 0.23 to 0.81 cm^3 cm^{-3} in the subsurface soil. The mean, standard deviation, variance and coefficient of variation were almost similar in both the layers (Table 6). The range indicated that the soils of the estate at different sections have wide differences in the maximum capacity to retain water. This is likely to cause an excess of water content in some of the sections, while soils of some of the sections are like to suffer from water deficit at some time of the year due to low saturation water content. The problem is more like to affect the sections at lower elevation where already the positional disadvantages have led to drastic affect on productivity. However, low standard deviation and consequently low coefficient of variation indicate that such patches with wide differences may be located to a very few small pockets. The variability is somewhat more in subsurface soil as compared to the surface soil. This variation may be because of poor structural development at subsurface soil as discussed earlier above.

The water retained by the soils at 10 kPa ranged from 0.30 $cm^{3}\cdot cm^{-3}$ to 0.64 cm^3 cm^{-3} in the surface soil, whereas it ranged from 0.31 cm^3 cm^{-3} to 0.61 cm^3 cm^{-3} in the subsurface soil. Thus, in case of water retained at 10 kPa too showed similar behaviour as that of saturation water content. The mean, standard deviation, variance and coefficient of variation are almost at par with each other in both the layers. The coefficient of variation values indicated low category of variability.

Water retained at 30 kPa pressure varied between 0.30 cm^3 cm^{-3} to 0.64 cm^3 cm^{-3} in the surface soil, with a mean value of 0.46 cm^3 cm^{-3}. The values obtained for the subsurface soils were almost at par with those obtained for the surface soil. The coefficient of variation values were 13.34 and 13.63 for both the two soil layers, respectively, and were almost at par with each other. The variability range observed are in accordance with those reported by others (Babalola, 1978; and Patgiri, 1993) for water retained by the soils at this tension at various soil depths. When a tension of 100 kPa was applied, the water retained by the surface soil ranged from a low of 0.18 cm^3 cm^{-3} to a high value of 0.52 cm^3 cm^{-3}

with a mean value of 0.35 cm^3 cm^{-3}, whereas for the subsurface soils the values ranged from a minimum of 0.18 cm^3 cm^{-3} to a maximum of 0.49 cm^3 cm^{-3}, with the corresponding mean value of 0.35 cm^3 cm^{-3}. The standard deviation and variance were homogeneous at both the soil depths and were in the low variability class as indicated by their low coefficient of variation. Thus, the soils can be assumed to be maintaining a homogeneity so far as the water retained at 100 kPa is considered.

When a tension of 300 kPa was applied the amount of water retained had a maximum value of 0.48 cm^3 cm^{-3} to a minimum of 0.02 cm^3 cm^{-3} in the surface soil; whereas, it ranged from a high of 0.42 cm^3 cm^{-3} to a value as low as 0.10 cm^3 cm^{-3} in the subsurface soil. The standard deviation, variance and coefficient of variation were all at par with each other for both the depths. Thus, the soils can be assumed to be maintaining a homogeneity so far as the water retained at 300 kPa is concerned. However, the values obtained are towards the higher side when compared with those obtained by Cameron (1978), but are in the lower side when the coefficient of variation are compared with those reported by Patgiri (1993). The standard deviation values obtained are very low than those reported by Patgiri (1993) but are higher than those reported by others (Gumaa, 1978). Thus, soils of different type, location and under management practices have different levels of variability. The soils being under perennial crops have low variability both in the vertical and horizontal direction.

When a tension of 1500 kPa was applied the water retained by the surface soil ranged from a high of 0.04 cm^3 cm^{-3} to a value as low as 0.04 cm^3 cm^{-3} with a mean value of 0.11 cm^3 cm^{-3}. The values ranged from a low of 0.04 cm^3 cm^{-3} to a high of 0.19 cm^3 cm^{-3} with a mean of 0.11 cm^3 cm^{-3} at the subsurface soil depth. The standard deviation and variance at both the depths had same values at both the soil depths and have medium range of variability as indicated by their corresponding coefficient of variation values 25.9 and 26.45 for the surface and subsurface soil depths, respectively. Thus, the soils maintained homogeneity in the vertical direction as indicated by their similar values of the statistical parameters.

The range of water content in all the depths for all the pressures applied are observed to be consistent (Table 6). All the statistical parameters are almost similar in their values. Homogeneity maintained in all the depths as indicated by the statistical parameters leads to conclude that the parameters have low variability. This may be attributed to the fact that tea being a deep rooted very long duration crop (> 40 years) the soils remains undisturbed for a long period which leads to maintain a homogeneity in soil making different soil properties to be of low variation. The coefficient of variation values had an increasing trend with increasing values of applied pressure (Patgiri, 1994), which indicates increase in variability amongst the pressures applied. This is an indication that soil would show greater variability when they are in the process of drying as that of wetting. This is more so because of the fact that the ground water table in the estate is in general shallow and all the sections receive water from nearly the same depth during the periods of high rainfall.

The various other retention parameters like water holding capacity, available water, readily available water, available water capacity and total available water capacity are computed from the data obtained at various pressures. The available water content ranged from 0.13 to 0.48 cm^3 cm^{-3} at surface soils and the subsurface soils too. The mean and standard deviation values too were nearly the same for both the soil depths. Similarly the coefficient of variation values (20.07 and 21.17, respectively at surface and subsurface soils) indicated a medium range of variability of the available water content.

Readily available water (RAW) content of the soils ranged from 0.01 to 0.29 cm^3 cm^{-3} at surface soil with a mean value of 0.11 cm^3 cm^{-3}. At subsurface soil the readily available water content ranged from 0.01 to 0.27cm^3 cm^{-3} with mean value of 0.1 cm^3 cm^{-3}. Thus, the range and mean values were nearly the same for both the soil depths indicating their equal distribution at both the depths. The coefficient of variation of readily available water was higher in the surface soil (54.91) as compared to that of the subsurface soil (51.70). This indicated a slight greater variability at surface soil as compared to subsurface soil.

Lesser variability of readily available water than that of available water, may be explained by the involvement of lower energetics of soil water in determining the readily available water content in soil as against available water.

The available water holding capacity (AWHC) ranged from a value as low as 0.06 $cm^3 cm^{-3}$ to a high of 0.23 $cm^3 \cdot cm^{-3}$ in the surface soil and from a low of 0.06 $cm^3 cm^{-3}$ to a high value of 0.22 $cm^3 cm^{-3}$ in the subsurface soil.

The mean, standard deviation, variance and coefficient of variation values are almost the same for both the soil depths. However, the coefficient of variation for AWHC was lower that of RAW. This indicates that when the total water content throughout the soil depth is considered, the variability decreases which may be due to lower variability of soil texture.

The total available water holding capacity (TAWHC) of the soils are calculated as per Eq. 7, it ranged from a high of 20 cm m^{-1} to a low of 6 cm m^{-1} with the corresponding mean of 13.28 cm m^{-1}.

The values indicates that the soils under study should not suffer from water deficit as the mean TAWHC value is of medium range, this is authenticated by the waterlogging condition of the estate. The standard deviation, variance and coefficient of variation are 0.065, 2.54 and 19.13 respectively; indicating an almost low variability.

Water transmission parameters

The values of saturated hydraulic conductivity (K_S) calculated as per Eq.2 ranged from a high of 7.6 cm hr^{-1} to a low of 0.08 cm.hr^{-1} in the surface soil layer. On the other hand it ranged from a high of 7.3 cm.hr^{-1} to a value as low as 0.06 cm. hr^{-1} in the subsurface soil. The corresponding mean values for the surface and subsurface layers were 3.62 cm hr^{-1} and 3.51 cm hr^{-1} respectively. This indicates that soil are in the moderate range of permeability class. Thus, the soils drain out the water at a moderate rate towards the main outlet. However, due to the locational disadvantage with respect to elevation, this water again reverts back into the sections due to the impeded drainage of the main outlet. This contributes to the rise in the ground water table in the soils of the estate. The standard deviation and variance are almost similar to each other (3.18 and 2.96) for the surface and subsurface layer, indicating a homogeneity in the vertical direction.

The weighted mean diffusivity of the samples ranged from a high of - 0.060 $cm^2 min^{-2}$ to a value as low as 0.0058 $cm^2 min^{-2}$ in the surface soil layer and ranged from a low of 0.0055 $cm^2 min^{-2}$ to a high of 0.059 $cm^2 min^{-2}$ in the subsurface soil layer with an average value of 0.030 $cm^2 min^{-2}$. The values of soil water diffusivity indicated very good amount of water flow at surface as compared to the slightly low rate of outflow in the subsurface soils. This is again a manifestation of the good structural development in the surface soils as compared to the subsurface soils, because the textural make of the soils at both the soil layers are nearly the same. The values indicated a good rate of flow of water under unsaturated condition indicating higher volume of flow under any circumstances. The values were in fact advantageous under the condition of a good outlet from the estate. However, the main drain carrying water out of the estate have been blocked due to human interference and this favourable soil property have not been able to stop the decline in the productivity of the sections. This is more so in sections at lower elevation.

The sorptivity values ranged from a maximum of 16.22 ml min^{-1} to minimum of 3.88 ml min^{-1} in the surface soil, whereas it ranged from a high of 14.87 ml min^{-1} to a low of 5.05 ml min^{-1} in the subsurface soil layer. In case of penetrability the values ranged from a high of 2.73 cm min^{-1} to a low of 1.14 cm min^{-1} in the surface soil; and from a low of 1.99 cm min^{-1} to a high value of 2.73 cm min^{-1} in the subsurface soil layer. These two parameters were also in the favourable range although these too have not been able to prevent a decline in the production of the estate due to waterlogging.

Air entry potential and pore interaction term – 'b' parameter

An important property of the soil with respect to water retention and transmission behaviour is the air entry potential. It indicates the amount of pressure to be applied for the flow process to start within the soil. This is an important behaviour of soil because the readiness of soil to release water and thereby its tendency to get dry depends much on this value. The higher the value of air entry potential, the more will be the tendency of the soil to remain wet for a longer period of time.

This has a strong detrimental effect on the tea crop specially during the period of high rainfall when waterlogging for a brief period is frequently observed. Under the condition of shallow ground water table, coupled with high air entry potential in those sections of the estate at lower elevation may also add to the reduction in the productivity of these sections.

Air entry values ranged from a high of 11.80 kPa to a value as low as 0.004 kPa at the surface soils and from 0.01 kPa to 12.70 kPa for the surface and subsurface soils, respectively. The mean air entry potential was slightly higher at surface soil (3.01) as compared to that of the subsurface soil (2.96). But the differences are small, indicating nearly similar levels of air entry potential. The mean values also indicate medium to high level of air entry potential. It would have been much more favourable to obtain air entry potential values below 2.0 in the soils of the estate considering its locational disadvantage. The air entry potential for these soils are thus slightly unfavourable making the soils to remain wet for long periods of time, affecting the crop. The standard deviation, variance and coefficient of variation were slightly higher at subsurface soil as compared to surface soils. This is again a manifestation of the poor structural development in the subsurface soils.

However, the soils under study maintains a homogeneity in the distribution of air entry potential. In recent years, the importance of the pore interaction term 'b' parameter is gaining popularity for providing vital information as regards to explaining unsaturated water retention as well as flow related processes/ relationships. This parameter can be utilized to solve many complex problems related to soil water retention and transmission that ultimately determines the drainage characteristics of soils. However, the estimation of the 'b'-parameter involves preparation of the soil water characteristic curve very accurately with the help of Pressure Plate Technique or other similar devices. These procedures are very high precision that requires sophisticated laboratory facilities which may not be easily available. Considering these difficulties, attempts in recent years have been made to determine the parameter from the soil texture data as these are routinely determined in any studies involving soil.

These mathematical models consider that the pore size distribution is a function of the soil texture and thus the 'b'-parameter too is a function of the distribution of sand, silt and clay. However, these models are not always successful especially in soils with very good structural development. As because these models donot take any role of the structural properties of soil into consideration, there is a possibility of failure at the level of forecasting the retention and transmission properties.

However, their good predictability has been reported by many workers (Zaman, 1991; Nayak, 1992; Sarma, 1991; Borkakoty, 1990). Based on these consideration the parameter have been computed by using three models as per Eq. 9, 10 and 11.

Table.1 Laboratory and field methods used for estimating the different soil parameters:

The methodologies used for estimating the different soil parameters are presented below

Property	Methods/Source
Mechanical analysis	International pipette method (Piper, 1966)
Bulk density	Core sampler (Black, 1965)
Moisture retention	Pressure plate technique (Richards,1948)
Hydraulic conductivity	Constant head method (Black,1965)
Weighted mean diffusivity	Bruce and Klute, (1965) and Crank (1956)
Organic carbon	Walkley and Black (Jackson, 1973) method
pH	Glass electrode (Jackson, 1973)
Water stable aggregates	Yoder's method
Saturated hydraulic conductivity (K_s)	Darcy's method as cited by Klute (1965)

Table.2 Range, mean, variance, standard deviation and coefficient of variation of soil parameters of Teok TE. "

Properties	Range	Mean	S. D ( )	Variance	CV
Bulk density					
0-30	1-1.61	1.47	0.074	0.0059	5.08
30-60	1.3-1.8	1.48	0.005	0.068	4.59
pH					
0-30	4.1-5.1	4.56	0.21	0.048 7	4.6
30-60	4.2-5.2	4.64	0.2	0.0414	4.31
OC					
0-30	0.31-0.81	0.57	0.1	0.01	17.54
30-60	0.41-0.96	0.57	0.11	0.01	17.54
Mean weight diameter (mm)					
0-30	0.15-1.11	0.64	0.03	0.168	25
30-60	0.10-0.6	0.28	0.018	0.136	48.57
Sand					
0-30	13.11-48.11	26.48	9.91	98.37	37.42
30-60	12.10-49.41	25.72	9.87	97.54	38.37
Silt					
0-30	8.77-55.12	35.12	10.81	117.05	30.78
30-60	6.71-59.23	35.42	11.15	124.45	31.47
Clay					
0-30	22.06-51.23	37.14	5.29	28.07	14.24
30-60	14.10-52.79	37.66	5.81	33.88	15.42

SWC					
0-30	0.30-0.73	0.53	0.07	0.006	13.2
30-60	0.23-0.81	0.53	0.09	0.007	16.26
SWCC 10kPa					
0-30	0.3-0.64	0.46	0.06	0.04	12.95
30-60	0.31-0.61	0.45	0.06	0.003	12.24
30 kPa					
0-30	0.29-0.59	0.41	0.05	0.003	13.34
30-60	0.27-0.59	0.41	0.06	0.003	13.63
100 kPa					
0-30	0.18-0.52	0.35	0.06	0.003	16.4
30-60	0.18-0.49	0.35	0.05	0.003	14.88
300 kPa					
0-30	0.02-0.48	0.28	0.07	0.004	23.46
30-60	0.10-0.42	0.28	0.07	0.004	21.39
1500 kPa					
0-30	0.04-0.21	0.11	0.03	0.0008	25.9
30-60	0.04-0.19	0.11	0.03	0.0008	26.45
AW					
0-30	0.13-0.48	0.3	0.06	0.003	20.07
30-60	0.13-0.48	0.3	0.06	0.004	21.17
RAW					
0-30	0.01-0.29	0.11	0.06	0.003	54.91
30-60	0.01-0.27	0.1	0.05	0.002	51.7
AWHC					
0-30	0.06-0.23	0.13	0.007	0.028	21.54
30-60	0.06-0.22	0.13	0.008	0.029	22.3
TAWHC					
0-30	6.0-20	13.28	2.54	0.065	19.13
K					
0-30	0.08-7.6	3.62	1.78	3.18	49.17
30-60	0.06-7.3	3.51	1.72	2.96	49
b-parameter Experimental					
0-30	1.67-8.45	3.15	0.83	0.69	26.35
30-60	1.85-7.33	3.18	0.83	0.7 26.1	
"b-parameter (Ghosh,1976)"					
0-30	0.34-13.37	4.14	3.04	9.26	73.42
30-60	0.28-13.87	4.47	3.25	11.06	72.71
"b-parameter (Ghosh,1980)"					

0-30	1.88-6.36	4.19	1.14	1.3	27.2	
30-60	1.65-6.36	4.26	1.18	1.39	27.7	
"b- parameter(Campbell,1985)"						
0-30	7.61-13.07	10.1	0.96	0.92	9.5	
30-60	6.43-13.43	10.23	1.03	1.07	10.06	
he						
0-30	.004-11.8	3.01	2.23	4.99	74.09	
30-60	.01-12.7	2.96	2.37	5.06	80.06	
IWC						
0-30	0.01-0.19	0.07	0.02	0.0005	30.49	
30-60	.01-.090	0.07	0.07	0.004	91.85	

Table.3 Mean, variance (σ), standard deviation (σ^2) and coefficient of variation (%) of soil properties of Teok tea estate requiring log transformation for obtaining normal distribution

Properties	Mean	Variance (σ)	Standard deviation (σ^2)	CV(%)
Ks				
0-30	1.13	0.38	0.62	54.86
30-60	1.10	0.38	0.61	55.45
Mean weight diameter				
0-30	-0.48	0.11	0.33	68.75
30-60	-1.37	0.28	0.47	34.30
Air entry potential				
0-30	0.75	1.04	1.02	136
30-60	0.71	1.05	1.02	143
RAW				
0-30	-2.43	0.54	0.73	30.04
30-60	-2.44	0.36	0.64	26.22
Experimental b –parameter (kPa)				
0-30	1.11	0.05	0.23	20.72
30-60	1.12	0.05	0.24	21.42

Table.4 Mean, median and mode of various soil parameters of Teok TE."

Properties	Mean	Mode	Median
BD			
0-30	1.47	1.46	1.46
30-60	1.48	1.48	1.48
pH			
0-30	4.56	4.56	4.55
30-60	4.65	4.65	4.65
OC			
0-30	0.57	0.56	0.54
30-60	0.57	0.56	0.54
Mean weight diameter			
0-30	0.65	0.2	0.25
Sand			
0-30	26.46	24.76	21.7
30-60	25.7	23.97	20.86
Silt			
0-30	35.34	33.21	29.33
30-60	35.69	33.38	29.19
Clay			
0-30	37.16	36.75	35.94
30-60	37.73	37.13	35.97
SWC			
0-30	0.53	0.52	0.51
30-60	0.53	0.52	0.51
SWCC 10 kPa			
0-30	0.46	0.45	0.44
30-60	0.45	0.45	0.44
30 kPa			
0-30	0.41	0.41	0.4
30-60	0.41	0.4	0.39
100 kPa			
0-30	0.35	0.34	0.33
30-60	0.35	0.34	0.34
300 kPa			
0-30	0.28	0.27	0.24
30-60	0.28	0.27	0.26
1500 kPa			
0-30	0.11	0.1	0.1

30-60	0.11	0.1	0.11	
AW				
0-30	0.3	0.29	0.28	
30-60	0.29	0.29	0.28	
RAW				
0-30	0.11	0.05	0.08	
30-60	0.1	0.06	0.08	
AWHC				
0-30	0.13	0.12	0.13	
30-60	0.13	0.12	0.13	
TAWHC				
0-30	13.28	13.03	12.51	
K				
0-30	3.7	3.1	2.11	
30-60	3.65	3.02	2.06	
b- parameter (Experimental)				
0-30	3.15	2.89	3.06	
30-60	3.17	2.9	3.08	
"b-parameter (Ghosh,1976)"				
0-30	4.54	1.14	2.8	
30-60	4.94	1.16	3.05	
"b-parameter (Ghosh,1980)"				
0-30	4.2	3.68	4.02	
30-60	4.28	3.71	4.08	
"b-parameter (Campbell,1985)"				
0-30	10.1	9.97	10.06	
30-60	10.23	10.07	10.18	
he				
0-30	3.59	0.74	2.12	
30-60	3.43	0.71	2.03	

Table.5 Comparisons of classical and kriging statistics

Properties	Mean		Variance		
	Classical	Kriged	Classical (σ^2)	Kriged (σ^2_k)	Ratio (σ^2/σ^2_k)
Mean weight diameter					
0-30	0.64	0.57	0.1668	0.036	4.66
30-60	0.28	0.224	0.136	0.0223	5.91
Saturation water content ($cm^3.cm^{-3}$)					
0-30	0.53	0.52	0.006	0.001	6.00
30-60	0.53	0.49	0.007	0.001	3.50
Water retained at 10 kPa ($cm^3.cm^{-3}$)					
0-30	0.46	0.42	0.04	0.011	3.63
30-60	0.45	0.45	0.003	0.0014	2.14
Water retained at 30 kPa ($cm^3.cm^{-3}$)					
0-30	0.41	0.40	0.003	0.0011	2.72
30-60	0.41	0.41	0.003	0.0015	2.00
Water retained at 100 kPa ($cm^3.cm^{-3}$)					
0-30	0.35	0.39	0.003	0.0014	2.14
30-60	0.35	0.36	0.003	0.0012	2.50
Water retained at 300 kPa ($cm^3.cm^{-3}$)					
0-30	0.28	0.27	0.004	0.0014	2.85
30-60	0.28	0.28	0.004	0.0016	2.50
Water retained at 1500 kPa ($cm^3.cm^{-3}$)					
0-30	0.11	0.11	0.0008	0.0002	4.00
30-60	0.11	0.11	0.0008	0.0002	4.00
Total available water holding capacity ($cm^3.m^{-1}$)					
0-30	13.28	12.16	0.065	0.002	32.50
Saturated hydraulic conductivity ($cm.hr^{-1}$)					
0-30	3.62	3.26	3.18	0.15	21.20
30-60	3.51	3.42	2.96	0.42	7.04
Experimental b-parameter					
0-30	3.15	3.15	0.69	0.61	1.13
30-60	3.18	3.17	0.70	0.23	3.04
Air entry potential (kPa)					
0-30	3.01	3.00	4.99	0.42	11.88
30-60	2.96	3.02	5.06	0.23	22.00

The b- parameter of the soils calculated from the experimental h curve ranged from 1.67 to 8.45 in the surface soil with a mean value of 3.15. The value of the parameter ranged from 1.85 to 7.33 in the subsurface soil, with a mean value of 3.18. The standard deviation, variance and coefficient of variation values (26.35 and 26.10 at surface and subsurface soils, respectively) observed were nearly the same at both the soil depths (Table 6). The values of coefficient of variation indicated that this parameter had a medium level of variability and follows the same trend as that of those of water retention values at different tension. This is as expected as because the water retention properties of the soils is the result of pore characteristics and the amount of water flowing out of the soil on application of increased pressure is directly determined by the pore size distribution (Baruah and Patgiri, 1996).

Values of b-parameters calculated with the empirical model using Eq.9 (Ghosh, 1976) utilizing data on sand, silt and clay content of soil ranged from 0.34 to 13.37 with a mean value of 4.14 at the surface soil, while in the subsurface soil the same ranged from 0.28 to 13.87 with mean of 4.47. The values were nearly the same with those computed from the observed soil water characteristic curve. However, the coefficient of variation were quite high at 73.42 and 72.71 per cent in the surface and sub-surface soils and hence they are log transformed to get a linear distribution of the observations (Table 7). This is an indication of the high variability of the estimated properties using empirical models. The coefficient of variation values observed conformity with those reported by Patgiri (1993).

Another ‘b’ parameter using Eq. 10 (Ghosh, 1980) ranged from 1.88 to 6.36 at surface soil with a mean value of 4.19. In the subsurface soil, it ranged from 1.65 to 6.36 with a mean of 4.26. These values too seemed to match well with the experimental values computed from the soil water characteristic curve. The means too were nearly similar to the experimental ones.

However, the coefficient of variation at 27.20 and 27.70 per cent at surface and subsurface soil, respectively, were low as compared to those from Eq. 9, but almost similar to those of experimentally observed values. Numerous reports (Zaman, 1991; Nayak, 1992; Patgiri, 1985) also suggested better fit of this model as compared to the earlier one. As such this model can well be used to compute complex soil parameters in absence of the experimental values. The high variability of the ‘b’-parameter with Eq. 9 could be explained in the light of the fact that while computing this b-parameter only the sand and silt fraction of the soil was considered neglecting the clay fraction which happens to be highly responsible in water retention (Zaman, 1991; Patgiri *et al.*, 1993). The coefficient of variation values of b-parameter (Ghosh, 1980) indicated a medium range of variability.

The other ‘b’-parameter using Eq. 11 (Cassel and Bauer, 1975) ranged from 7.60 to 13.07 with corresponding mean values of 10.10 at surface soil, while at subsurface soil the range was from 6.43 to 13.43 with mean value of 10.23. The coefficient of variation values of 9.50 and 10.06 for the surface soil and subsurface soil indicating a low variability. The standard deviation, variance and co-efficient of variation values are found to be nearly the same at both the soil depths.

The importance of silt can be clearly observed when the experimental and the b-parameter reported after applying Ghosh (1980) (Eq.10) model are compared. They are conclusively similar to each other. This similarity can be attributed to the fact that in Eq. 10 all the three soil separates are taken into consideration while calculating the b-parameter. This result can be more elaborately explained by the fact that the silt content of the soils under study are > 4 per cent. Since it was reported that silt content of the soil < 4 per cent happens to be the limiting factor for utilizing the Eq. 10 (Zaman, 1991). Except for the coefficient of variation values obtained from Eq. 9 all the other ‘b’-parameters could be grouped.

Comparison of classical and kriging statistics

A comparative assessment of classical and kriging statistics were made in order to verify the effectiveness of the kriging technique. For this mean and the variance of the techniques were compared. The mean of the kriged values for the indicated properties were computed for comparison. The estimation variance was computed out of the kriging variances. The mean and variance was computed out of the two techniques along with the ratio of the population variance (σ^2) to kriged variance (σ^2_k) are presented in Table 5. This ratio was used as the indicator for determining the efficiency of the kriging system under the condition that a value >1 indicates greater efficiency of the kriging technique over the classical technique.

It is seen from Table 5 that the mean computed from the original observations and the kriged values matched well, indicating that kriging can precisely estimate data for the properties assuming that the classical mean is true. The difference although exists in some case, are either zero or very negligible. This fulfils the criterion of unbiasedness. However, the estimation variance in the two techniques differ considerably. In general, the estimation variance in the kriging technique was always lower than the classical technique. The ratio of (σ^2) to (σ^2_k) varied from 2.14 to 32.50 for the indicated soil properties. Similar findings indicating greater efficiency of the kriging system were earlier reported by Kalita (1988); Anlauf (1988) and Patgiri (1993).

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How to cite this article:

Abu Syed Nuruz Zaman and Patgiri, D. K. 2023. Comparison of Soil Properties of a Tea Estate using Classical and Geostatistical Technique. *Int.J.Curr.Microbiol.App.Sci.* 12(05): 199-217.
doi: https://doi.org/10.20546/ijcmas.2023.1205.026