

Therefore, keeping cost of production in view, coco peat : rice husk : FYM (1:2:1) may be recommended for commercial production of *Gerbera jamesonii* cv. Zingaro.

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MULTIVARIATE ANALYSIS TO DETERMINE SOIL HARD PAN LAYER

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Abstract

Soil compaction of agricultural soil is an increasingly challenging worldwide problem for crop production and environment. To remove the hard pan layer sub-soiling of the field is necessary to increase the production of the crop. It is need to know the hard pan depth of the agricultural soil. To determine hard pan layer multivariate analysis technique was used: Principal component analysis was used to calculate bulk density index, which is the indication of hard pan layer. To determine bulk density index the soil parameters bulk density was considered. To determine soil bulk density a field experiment was conducted to determine the extent of sub-soil compaction due to different number of passes i.e. 1, 6, 11 and 16 at varying normal loads of 4.40, 6.40 and 8.40 kN on test tractor. The soil bulk density and penetration resistance at different depth were measured. The highest bulk density index of 1.0 was observed at 15-20 cm soil depth. Bulk density index were decreased with increase in soil depth. The bulk density index was lowest at 0-5 cm soil depth due to increase in number of passes die soil was loosened.

Key words : Bulk density index, Principal components analysis, Variance Covariance Matrix.

1. Introduction

In India, due to increasing use of tractors and machinery system particularly rotivator, laser leveler and balers the production of high power (>45 kW) tractors is increasing [Singh and Mani (2009)] which may aggravate the problem of hard pan formation particularly in loam and clay loam soil condition. The adverse effect of hard pan includes limited nutrient intake, reduced infiltration and reduced exchange of air and gases which may lead to less emergence of seedling and improper development of root [Arvidsson *et al.* (2001) and Ishaq *et al.* (2001)]. This finally results into poor yield of crops [Arvidsson *et al.* (2001), Radford *et al.* (2001), Dauda and Samari (2002)]. The mechanization is need of the hour; so heavy machine with their power source will increase; the power availability is to increase 3.0 kW/ha by 2050 [Singh and Mani (2009)]. So, the problem of subsoil compaction will further increase.

As sub-soil compaction leads to different adverse effects like high bulk density, high penetration resistance, reduced root development and reduced yield. The dry bulk density is commonly used to characterize the state of soil compactness. However, these properties have a limited value for comparison of the state of compaction between soil types. Generally, actual bulk density is expressed as a percentage of some reference compaction state of given soil and called degree of compactness or relative compactness. The degree of compactness proposed by Hakansson (1990) is defined as the ratio of the actual bulk density to the reference bulk density obtained by uniaxial compression of wet soil (sufficiently for drainage) at a static pressure of 200 kPa. Another relative compaction value is the ratio of actual bulk density and maximum bulk density obtained in the Proctor compaction test, in which a constant energy (by a falling weight) is applied at different water contents. This ratio has been useful to characterize soil compaction in field studies [Pidgeon and Soane (1977), Carter (1990) and Da Silva *et al.* (1994)]. The Proctor test is recommended for homogenized soil material in studies of the effect of water content and soil composition on soil compactability [Horn and Lebert (1994)]. In the approach of Bennie (1991), the relative bulk density index was defined as :

$$= \frac{(\rho_{\text{actual}} - \rho_{\text{min}})}{(\rho_{\text{max}} - \rho_{\text{min}})}$$

Where, ρ is the bulk density; the maximum bulk density (ρ_{max}) is determined with the Proctor test; and ρ_{min} is the minimum bulk density from the mass of unsieved dry soil needed to fill a container of known volume.

The relative compaction parameters are more useful than bulk density or porosity in studies of the effects of field traffic on soil conditions and root and crop response [Canarache (1991), Hakansson and Lipiec (2000)]. The relative compaction was also suitable input parameter in modelling response of root growth, leaf area and crop yield to soil compactness in various soil-climate combinations [Arvidsson and Hakansson (1991), Simota *et al.* (2000)]. Monnier *et al.* (1973) proposed another concept based on structural and textural porosity. In this paper, we tried to develop the soil bulk density index by statistical method which is relevant to reflect the depth of sub-soiler operation.

2. Materials and Methods

The bulk density index was developed based on the data obtained in a field experiment, conducted to determine the effect of different normal loads on a test tractor (weight 15.76 kN, power 26 kW) and its frequency on soil compaction, carried out in the experimental farm at Indian Agricultural Research Institute, New Delhi. The soil of the experimental site was alluvial and had sandy loam texture with fine sand as major constituent up to depth of 0-93 cm which increased with depth from 49.00 to 53.75% : coarse silt and fine silt decreased from 24 to 21% and 11.5 to 9.63%, respectively in the same depth.

2.1 Experimental Procedure

The test was conducted on experimental tractor with three normal loads of 4.4, 6.40 and 8.40 kN and 1, 6, 11 and 16 number of passes of test tractor with three replications. The soil sample for bulk density was collected to determine depth of hard pan layer. To begin with, tractor with an effective normal load of 4.4 kN was run, at a forward speed of 3 km/h, for one number of passes. To determine bulk density soil samples were collected upto a total depth of 50 cm at an interval of 5 cm. Thus, at one location a total of 10 samples were collected. All cares were taken to take samples from respective depths only. Following this the test tractor was run for same number of passes with an effective normal load 6.40 kN on rear tire and soil sample for bulk density were collected. In next round of experiments, effective normal load 8.40 kN was taken and same number of test run were made and after each test run combination bulk density and penetration resistance measured. To ascertain the impact of frequency of passes on compaction of sub soil layer, the observations on soil bulk density and cone penetrometer resistance were taken at different depth upto 50 cm. Thus, a total of 36 sets of experiments were conducted by taking three normal loads and four different passes and three replications of each test run and observation on compaction parameters were collected.

2.2 Development of Bulk Density Index

Bulk density index was developed to obtain a single factor to define influence of soil compaction on growth and crop yield. There are various methods such as AHP (Analytical Hierarchy Process), Mixture Analysis, Principle Component Analysis and some other techniques used for developing composite index. In the present study, principle component analysis was used for development of bulk density index as per the determination of hard pan layer.

Methodology of construction of bulk density index

The bulk density index was constructed using bulk density. Following standard methodology based on theoretical framework, a meaningful bulk density index was developed for combining each combination of compaction (load and passes). Following steps were followed in constructing development of index :

Bulk density at different depth corresponding to each treatment were required. For development bulk density index were selected on the basis of their analytical soundness, measurability, coverage, relevance to the influence of compaction in sub-soil. The average bulk density data was normalized. Normalization played a vital role in standardizing the data. Prior to any data aggregation as the variables often had different measurement units it is necessary to normalize data. To make the data unit free normalisation is used. Out of different normalisation methods, here standardization technique was used.

$$Z_q = \frac{X_{qj} - \mu_q}{\sigma_q} \quad (2.2.1)$$

Where,

X_{iq} is a value for qth variable in ith combinations.

μ_q is mean of qth variable.

and σ_q is standard deviation of qth variable.

Z_q is standardized values of qth variable.

Principal Component Analysis : It is a mathematical procedure that transforms a number of possibly correlated variables into a smaller number of uncorrelated variables called principal components. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible.

An exploratory analysis should investigate the overall structure of the indicators, assess the suitability of the data set and explain the methodological choices, e.g., weighting aggregation. When variables are correlated, multivariate analysis can be used in finding weights.

(a) First of all maximum likelihood estimate of variance-covariance matrix (S) was estimated, using the following relationship.

$$\hat{\Sigma} = \frac{1}{n} E(X - \bar{X})(X - \bar{X})' \quad (2.2.2)$$

Where,

X = column vector of variables

= average column vector of variables

$\hat{\Sigma}$ = M.L.E of variance-covariance matrix.

(b) Next, using the following relationship the correlation matrix (CM) was obtained from above variance-covariance matrix

$$CM = (\sqrt{V})^{-1} \hat{\Sigma} (\sqrt{V})^{-1} \quad (2.2.3)$$

Where,

CM = correlation matrix, V = diagonal matrix obtained from variance-covariance matrix.

(c) Then, Eigen values and Eigen vectors of the correlation matrix were obtained.

Development of Bulk Density Index

The bulk density index (BDI) was developed by substituting the Eigen values and principal components obtained from correlation matrix of variables respectively in the equation given below :

$$BDI = \frac{\lambda_1 Z_1 + \lambda_2 Z_2 + \dots + \lambda_q Z_q}{\sum_{i=1}^q \lambda_i} \quad (2.2.4)$$

The principal components were obtained by using the following equations calculation:

$$Z_1 = a_{11}x_1 + a_{12}x_2 + \dots + a_{1q}x_q$$

$$Z_2 = a_{21}x_1 + a_{22}x_2 + \dots + a_{2q}x_q$$

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$$Z_q = a_{q1}x_1 + a_{q2}x_2 + \dots + a_{qq}x_q \quad (2.2.5)$$

Where, BDI_c is bulk density index for cth compaction combination, λ_j are eigen values, Z_j are principal components, x_j 's are standardized values of variable and a_{ij} is an element belonging to ith eigenvector and for jth variable.

After this, the bulk density index of each treatment combinations were normalized by using given formula

$$BDI_{Nc} = \frac{BDI_c - \min(BDI)}{\max(BDI) - \min(BDI)} \quad (2.2.6)$$

Where, BDI_{Nc} is normalized value of bulk density index of cth compaction combination, $\min(BDI)$ is minimum value of bulk density index and $\max(BDI)$ is maximum value of bulk density index.

Bulk density index based on treatment

For every set of experiment with varying normal load on tractor and its number of passes, depthwise different bulk density were obtained. The depth of most compacted layers having maximum bulk density in different treatment plots. The depth of most compacted layer was important to decide the depth of sub-soiling for a compacted sub-soil layer. To determine this layer for different treatments, principal component analysis was used considering the different level of study variables i.e. amount of normal load on test tractor and its frequency of passages on compaction properties e.g. bulk density. The principal component analysis, aimed at giving appropriate importance to different factors based on the actual attribute of each component. The analysis automatically generated weights for different component based on their correlation and the analysis investigated the overall structure of data sets and gave all maximum likelihood estimates of variance-covariance matrix. Based on variance co-variance matrix, correlation matrix for different compaction combination was developed. The bulk density index based on treatment was developed using Eigen values, Eigen vectors and principle components were obtained from correlation matrix. To bring the index value, between 0 to 1, the normalized value of the bulk density index based on treatment was determined using minimum and maximum values of bulk density index of compaction combinations. The index value 1 indicated the most compacted layer of the soil depth considering highest bulk density index. The soil depth layer having

maximum index were found to be most compacted layer of the soil. Values of the index <0.5, 0.5-0.6, 0.6-0.7 and >0.7 correspond to low, medium, high and very high degrees of compaction respectively. For classifying the compaction combinations in terms of very high, high, medium and low compaction, the above given index data was arranged in ascending order with their treatment.

Ranking for classification of bulk density index

After development of bulk density index for different level of compaction combinations the values of the index lies between 0 to 1. The value 1 indicates highest compaction and 0 indicate the lowest compaction among the given compaction combinations for all the values. Values of the index < 0.5, 0.5-0.6, 0.6-0.7 and >0.7 correspond to low, medium, high and very high degrees of compaction, respectively. For classifying the compaction combination in terms of very high, medium and low compaction, the above given index data was arranged in ascending order with their treatment.

3. Results and Discussion

Bulk density index

The bulk density index will depend upon its soil physical properties such as bulk density [Canillas and Salokhe (2002)]. To account for, the influence of different levels of normal load on test tractor and its passages on performance parameters, bulk density index was developed. The variance-covariance and correlation matrix are given in Tables 1, 2 and 3.

The highest value of bulk density coefficient was ranked 1 for, 15-20 cm soil depth layer, so, this was the most compacted soil layer: followed by 20-25 cm and 25-30 cm soil depth layers (Table 4). The lowest value of the index was at 0-5 cm i.e. at surface layer of the soil considering the different treatments. Thus, the bulk density coefficient reconfirmed that maximum normal load on rear wheel with its largest number of passes caused maximum sub-surface soil condition at sub-soil depth of 15-20 cm.

Similarly, the bulk density index between 0.60-0.70 was termed as high compacted layer. The high sub-soil compacted layer was at 20-25 cm soil depth. Akin to above the soil depth layer 25-30 cm lies in the category of medium compacted layer with bulk density index 0.5236. Thus, beyond 30 cm the compaction decreased with increase in depth (Table 4). Generally, medium compaction was caused by treatment combinations of high load and less number of passes or low load with large number of passes.

4. Concluding Remarks

1. The highest value of bulk density index was obtained at sub-soil depth layer of 15-20 cm.
2. The bulk density index reconfirmed that maximum additional normal load of 4.00 kN on rear wheel and largest number of passes caused maximum sub-surface soil compaction.
3. Sub-soil bulk density index of 0 and 1 corresponded to soil bulk density of 1.85 Mg/m³ and 1.30 Mg/m³, respectively which were assumed the limiting factor for index determination.

Table 1: Variance covariance matrix of bulk density and treatment.

	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇	T ₈	T ₉	T ₁₀	T ₁₁	T ₁₂	T ₁₃
D ₁	0.00067	0.00059	0.00096	0.00091	0.00063	0.00069	0.00096	0.00091	0.00061	-0.00063	0.00103	0.00096	
D ₂	-	0.00087	0.00090	0.00092	0.00072	0.00094	0.00086	0.00090	0.00057	0.00091	0.00095	0.00105	
D ₃	-	-	0.00147	0.00134	0.00092	0.00104	0.00142	0.00136	0.00084	0.00090	0.00147	0.00131	
D ₄	-	-	-	0.00131	0.00090	0.00106	0.00131	0.00128	0.00082	0.00098	0.00140	0.00134	
D ₅	-	-	-	-	0.00069	0.00081	0.00090	0.00091	0.00061	0.00077	0.00101	0.00102	
D ₆	-	-	-	-	-	0.00103	0.00100	0.00103	0.00065	0.00100	0.00110	0.00117	
D ₇	-	-	-	-	-	-	0.00145	0.00132	0.00088	0.00087	0.00153	0.00134	
D ₈	-	-	-	-	-	-	-	0.00129	0.00382	0.00092	0.00142	0.00132	
D ₉	-	-	-	-	-	-	-	-	0.00362	0.00061	0.00099	0.00096	
D ₁₀	-	-	-	-	-	-	-	-	-	0.00102	0.00099	0.00116	

T₁ = L₁P₁T₂ = L₁P₂ T₃ = L₁P₃ T₄ = L₁P₄ T₅ = L₁P₅ T₆ = L₂P₁ T₇ = L₂P₂ T₈ = L₂P₃ T₉ = L₂P₄ T₁₀ = L₂P₅ T₁₁ = L₃P₁ T₁₂ = L₃P₂ T₁₃ = L₃P₃

Table 2 : Correlation matrix of bulk density and treatment.

	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇	T ₈	T ₉	T ₁₀	T ₁₁	T ₁₂	T ₁₃
D ₁	1.0000	0.7783	0.9609	0.9705	0.9277	0.8337	0.9682	0.9771	0.9483	0.7640	0.9555	0.9264	
D ₂	-	1.0000	0.7946	0.8646	0.9340	0.9897	0.7650	0.8474	0.7800	0.9674	0.7755	0.8870	
D ₃	-	-	1.0000	0.9681	0.9087	0.8422	0.9711	0.9860	0.8765	0.7339	0.9245	0.8528	
D ₄	-	-	-	1.0000	0.9440	0.9073	0.9513	0.9813	0.9136	0.8446	0.9220	0.9279	
D ₅	-	-	-	-	1.0000	0.9535	0.9024	0.9575	0.9504	0.9107	0.9215	0.9723	
D ₆	-	-	-	-	-	1.0000	0.8141	0.8886	0.8098	0.9735	0.8244	0.9101	
D ₇	-	-	-	-	-	-	1.0000	0.9627	0.9254	0.7121	0.9682	0.8769	
D ₈	-	-	-	-	-	-	-	1.0000	0.9223	0.8021	0.9488	0.9173	
D ₉	-	-	-	-	-	-	-	-	1.0000	0.7690	0.9612	0.9653	
D ₁₀	-	-	-	-	-	-	-	-	-	1.0000	0.7455	0.9032	

Table 3: Eigen values and Eigen vectors of bulk density and treatment.

Eigen value	Eigen vector								
	PC ₁	PC ₂	PC ₃	PC ₄	PC ₅	PC ₆	PC ₇	PC ₈	PC ₉
10.1221	0.2929	-0.2540	-0.0116	-0.4421	0.0389	-0.1682	0.4123	-0.5929	0.1320
0.7459	0.2753	0.4579	0.1611	0.3256	-0.1877	0.3999	0.1589	-0.4037	0.0022
0.2287	0.2878	-0.2456	0.4716	-0.0517	-0.2057	0.0419	-0.0499	0.4179	0.4814
0.0686	0.2979	-0.0769	0.2166	-0.3948	0.3293	0.2153	-0.4948	0.0538	-0.4799
0.0420	0.2992	0.1137	-0.0937	0.1330	-0.5119	-0.2461	0.2660	0.2792	-0.4646
0.0223	0.2851	0.3742	0.1972	0.1555	0.1356	-0.1410	0.0813	-0.2104	0.1390
0.0156	0.2878	-0.3178	0.1488	0.3180	0.3060	0.4169	0.5183	0.1388	-0.2066
0.0068	0.2976	-0.1487	0.2288	-0.0916	-0.3662	0.2783	-0.2462	-0.1129	-0.0347
0.0021	0.2873	-0.1912	-0.5529	0.0316	-0.1712	0.3882	-0.2194	0.0220	0.3807

*PC = Principal Component.

Table 4: Bulk density index (BDI) at different depth layer.

Rank	Soil depth layer, cm	Bulk density index	Compaction level
1	15-20	1.0000	Very high
2	20-25	0.6252	High
3	25-30	0.5236	Medium
4	30-35	0.4620	Low
5	35-40	0.3580	
6	10-15	0.3575	
7	40-45	0.2916	
8	10-15	0.1177	
9	45-50	0.1100	
10	0-5	0.0000	

4. Single passages of tractor has no effect on subsoil properties

5. The lowest normal load caused appreciably comparable subsoil compaction at maximum number of passes thus; multiple passes should be avoided even when tractor weight is lower.

6. Compaction due to high load and less number of passes and low load with high passes caused, low and high sub-soil compaction.

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