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Research Article

MEASUREMENT OF SOIL CONE INDEX IN WET RICE FIELD SOIL USING DIGITAL HAND-HELD CONE PENETROMETER

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Abstract- Soil cone index (CI) is a soil mechanical property widely used to assess soil strength in tillage research. In this study, physical properties of soil and penetration resistance of soil were measured at four locations *viz.,* namely Wet land and Paddy Breeding Station of Tamil Nadu Agricultural University- Coimbatore (CWL to C-PBS) and at Aduthurai and Bhavanisagar (ADT and BSR) under wet rice field condition, like those encounters by tractor at start of puddling operation. Bulk density varied with depth; and hence samples were taken at two depths of 0 to 10 cm and 10 to 20 cm. Values of Cone Index decreased with the increase in moisture content. Contrary to the effect of moisture content on Cone Index, values of Cone Index tended to increase with the increase in bulk density under both layer. An instrumented electronic hand-held cone penetrometer with a cone base area of 7.8 cm^2 was developed to record the strength of rice soil. The penetration resistance in the upper layer varied from 13.63 to 35 kPa in C-WL and 6.3 to 40.57 kPa in C-PBS. Penetration resistance in the lower layer varied between145.03 and 200.36 kPa in C-WL and 88.17 and 200.64 kPa in C-PBS. In case of ADT and BSR sites, the soil strength profile was observed to be uniform and average penetration resistance in 0 to 30 cm depth varied from 67.66 to 166.73 kPa and 75.91 to 169.85 kPa respectively.

Keywords: SoilCone Index, Bulk Density, Moisture Content and Traction.

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Introduction

Cone penetrometer can be defined as a device which measures the force required to insert a cone into the soil. It is an easy and quick tool to measure relative soil strength. It is used for soil characterization in traction prediction modelling. Soil cone penetrometer have numerous applications in agriculture and off-road traffic studies that include in-situ measurements in layered soils, predicting the depth of the compacted layer for precision tillage, predicting trafficability and bearing capacity for soil research [4]and simulation of root growth [6]. In 1846, the French engineer Collin developed a 1mm diameter needle shaped penetrometer to estimate the cohesion of different types of clay [5]. The Waterways Experiment Station (WES, 1948) later developed a circular cone penetrometer with an apex angle of 30^0 and base area of 1.61 cm^2 that was mounted on a graduated shaft of 0.95 cm diameter and 91.4 cm length [4] and [5]. The American Society of Agricultural and Biological Engineering (ASABE) has established standards for a 30^0-circular stainless steel cone penetrometer and the procedure for using and reporting data obtained with the soil cone penetrometer [1] and [2]. The standard [1] recommended two standard cones, 20.27 mm diameter cone base with 15.88 mm diameter shaft for soft soils; and 12.83 mm diameter cone base with 9.53 mm diameter shaft for hard soils [Fig-1]. This ASAE Standard also specifies the index of application range for different penetrometer types, penetration speed and depth increments for soil characterization.

The main objective of this study is to give a complete picture of soil physical property and cone index. It is also used to as an indicator of soil resistance and provides reference for comparison between different sites. It enables the development of traction models based on penetrating resistance.

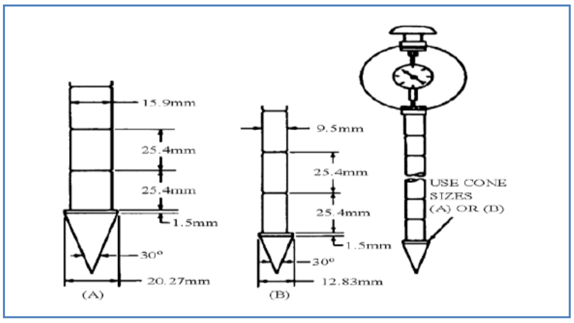

Fig-1 Cone penetrometer standardized by the ASAE

Materials and Methods

In this study, Physical properties of soil and penetration resistance of soil were measured at four locations *viz*., namely Wetland and Paddy Breeding Station of Tamil Nadu Agricultural University, Coimbatore (C-WL to C-PBS) and at Aduthurai and Bhavanisagar (ADT and BSR) under wet rice field condition, like those encounters by tractor at start of puddling operation [Fig-2]. The four locations represent three typical geographical area were rice is cultivated in Tamil Nadu.

Physical properties of the Soil

Physical properties of soil were measured to relate the conditions among different fields and also to serve as reference value for future comparisons and comparisons with works of other researchers.

C-PBS

C-WL

ADT

BSR

Fig-2 Typical field condition at different locations

Soil Texture Analysis

Before the field tests, the soil sample were randomly collected from the test plot for classification. The international pipette method was used to classify the soil according to United States Department of Agriculture (USDA) textural triangle for soil classification [3].

Moisture content

The test soil samples were collected from the rice fields with standing rice stubble. The fields were flooded with standing water and after 24 hours the experiments were conducted. The undisturbed soil sample was scooped up and free water could drain and samples were collected in containers which were used for measurement of moisture content and bulk density. Soil samples were collected at depths of 0 to 10 cm and 10 to 20 cm. These samples were weighed and then oven dried at oven at 105 °C for about 24 hours. After the specified time, the oven-dried samples were weighed. The moisture content on wet basis was calculated as

$$M.C_{(wb)} = \frac{W_w - W_d}{W_w} X100 \quad ....[1]$$

Where,

$M.C_{(wb)}$ = Soil moisture content, wet basis (%)

W_w= Weight of the wet sample (g) and

W_d = Weight of the oven dried sample (g)

Bulk density

Bulk density is the mass per unit volume of soil including pore space. Measurement of bulk density was carried out in all the experimental sites. Since the soil is saturated clay, bulk density is affected by sampling process. Since bulk density varies with depth, samples were taken at two depths of 0 to 10 cm and 10 to 20 cm. Soil sample was manually filled in cylindrical aluminium cups to measure the bulk density. The volume of container was around 100 cm^3, whenever bulk density was measured measurement of moisture content was also made simultaneously.

$$\text{Bulk density,}(g\text{-}cm^{-3}) = \frac{\text{Mass of soil sample, (g)}}{\text{volume of container, } (cm^3)} \quad ....[2]$$

In each field, four replicated observations were made. Since the upper and lower layers of the fields exhibit typically different experimental behaviour, measurement of moisture content and bulk density were done separately for each of these layers. From these values the volumetric water content and gravimetric water content in each field was calculated.

Soil Cone Index/Penetration resistance

Cone index represents the average penetration force per unit projected cone base area exerted by soil upon the conical head when forced down a specific depth. Cone index values usually used for traction prediction are the average values recorded over a depth corresponding to a maximum tyre sinkage. Bearing capacity is affected by soil-water content and by soil management. Therefore, it differs between dry and wet seasons and in response to irrigation, drainage (including mid-season drainage) and land preparation, and may differ between neighbouring plots. Soil water and management also affect the cone index of resistance to penetration, and the seasonal changes in cone index may be different at different depths. Measurement of soil strength in saturated rice field condition with available cone penetrometer at a depth is quite difficult due to the weak nature of soil. To obtain significant penetration resistance a cone with large base area was used. The cone had an apex angle of 30^0 and a base area of 774 mm^2 (314mm diameter) that was mounted on a graduated shaft of 16 mm diameter and 730 mm length [Fig-3]. Cone fixed to the end of a rod was pushed into the soil and penetration resistance in terms of force was measured as a function of the depth of penetration using digital cone penetrometer.

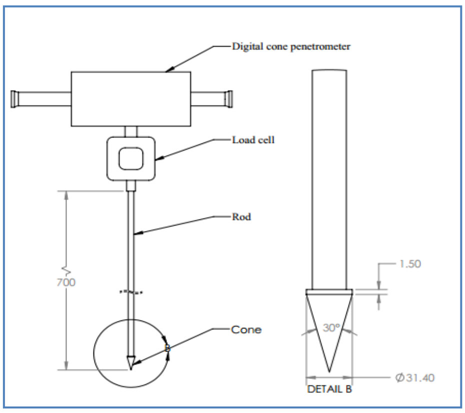

Fig-3Cone penetrometer

Cone penetrometer

Hand held digital cone penetrometer was used to measure the strength of soil with respect to depth [Fig-4]. Specification of the instrument is given in the [Table-1].

Fig-4 Digital cone penetrometer

Table-1 *Specification of the instrument*

Sl. No.	Particulars	Specifications
1.	Make	Indus (Indus Electronics India (p).Ltd)
2.	Model	CPM 84
3.	Load capacity	0 to 200 kg
4.	Distance measurement	0 to 400 mm incremental depth of 5 to10 mm adjustable
5.	Number of readings per penetration	Maximum 50
6	Possible number of data sets	100 X 30 sets of readings per location
.7.	Operator interface	Membrane keypad
8.	Display	LCD panel
9.	Options	Record, View, Delete and Transfer
10.	Data communication	USB port
11	Data Retrieval and Processing Software	Cone Penetrometer 4.1

Description of the Equipment

The electronic cone penetrometer was specifically developed for carrying out this study. The specifications and requirements were provided and the equipment was developed, fabricated, and tested by Indus Electronics India (P) Ltd.

Weight of equipment excluding penetrometer probes is 1.04 kg. The equipment has provision for continuous recording of soil strength profile and can store up to 3000 sets of reading (100 replication X 30 sets of reading per location). 200 kg capacity S type load cell measured the penetration resistance. An ultrasonic sensor is used to measure the distance between the device and soil surface. For proper function of this instrument, the ultra-sonic beam should be reflected from the ground to the receiver. To ensure this, target plate of 300 mm X 300 mm with the central hole is first placed on the ground before the measurement is done. When the measurements are carried out in rice fields with standing water, a small platform is used to support the target plate.

The data are transferred to computer using data acquisition software and stored as Excel files. The data labels include date, time, replication number, count, average penetration resistance, depth, and force.

Procedure

1. The required probe (cone penetrometer cylindrical sinkage rod) is attached to the penetrometer. The target platform is placed in location where measurement is made.
2. The penetrometer is positioned with the base of the cone or tip of the sinkage rod at the ground level and the start button is pressed. This signal start the of recording. As the probe is pushed into the soil, the depth and force readings are continuously monitored in the penetrometer display.

The force values are recorded at every depth increment of approximately 10 mm. When the maximum depth or maximum penetration resistance for manual pushing is reached, the start button is pressed again to signal the end of the measurement. The penetrometer is gently pulled out by holding the cone penetrometer rod to prevent damage to the instrument.

Result and Discussion

Soil Physical Properties

Based on the textural classification, the soils in the above locations of experimental fields are classified as shown in [Table-2]

Table-2 *Textural soil classification of experimental field*

Location	Field No.	Clay (%)	Silt (%)	Sand (coarse + fine) (%)	Soil Texture
C-WL	M4	23.4	20	56.6	Sandy Clay Loam
	M2	25.9	20	54.1	Sandy Clay Loam
C-PBS	L1	32.5	20.9	46.6	Clay Loam
	H1a	35.9	20	44.1	Clay Loam
ADT	F1	63	12	25	Clay
	F2	62	14	24	Clay
BSR	A1	30	4	66	Sandy Clay Loam
	A2	25.29	3	68	Sandy Clay Loam

Measurement of volumetric water content gives a better inference about the nature of soil. The volumetric water content and gravimetric water content in each field was calculated and was shown in [Table-3]. It was observed that moisture content on the volumetric basis varied from 53.6 to 75.7 %. This implies that the soil matrix is filled mostly with water under different field condition. Since more than 50 % of soil is filled with water, it is expected to be softer and may behave as a semi solid. The moisture content of the lower layer is mostly in the range between 28.6 and 36.9 % while moisture content of upper layer is 35.5 to 56.1 %. It clearly shows that the lower layer has lesser volume of water than the upper layer. Hence the soft nature of upper layer may be attributed to the capillary pores and macro pores that are filled with water that predominate the upper layer when compared to the lower layer.

The bulk density of upper soil layer was always found to be less than the lower layer. The bulk density of upper layer showed wide variation and varied between 1.20 to 1.56 g/cm^3 for the fields at C-WL and C-PBS. However, in the BSR and ADT sites, the bulk density varied between 1.65 and 1.77 g/cm^3. The bulk density in the lower layer varied from 1.52 to 1.72 g/cm^3 for C-WL and C-PBS sites, while for BSR it varied from 1.72 to 1.86 g/cm^3 and for ADT from 1.82 to 1.99 g/cm^3 [Table-3]. It is very clear from these that lower soil layers exhibited minimum variation in each field condition. It was also observed that the ratio of bulk density in upper and lower soil layers in case of ADT and BSR was 1.05, meaning that the upper and lower layers were almost identical. However, the bulk density of lower soil layer in C-WL and C-PBS was approximately 1.5 times the bulk density of the upper layer, meaning that in such soil condition upper and lower layer behave differently.

Table-3 *Gravimetric and volumetric water content for experimental field*

Location	Field No.	Upper layer (Depth 0 to 10 cm)					Lower layer (Depth 10 to 20 cm)				
		Bulk Density (g/cm3)	Water content by Mass basis (%)		Water content by Volume basis (%)		Bulk Density (g/cm3)	Water content by Mass basis (%)		Water content by Volume basis (%)	
			Water content (w.b%)	Solid content	Water content	Solid content		Water content (w.b%)	Solid content	Water content	Solid content
C-WL	M4	1.53	35.5	64.5	54.3	45.7	1.67	28.6	71.4	47.8	52.2
	M2	1.36	39.4	60.6	53.6	46.4	1.61	33.5	66.5	53.9	46.1
C-PBS	H1a	1.3	50.6	49.4	65.8	34.2	1.67	35.3	64.7	59	41
	L1	1.23	56.1	43.9	69	31	1.54	36.9	63.1	56.8	43.2
ADT	F1	1.69	44.8	55.2	75.7	24.3	1.91	31	69	59.2	40.8
	F2	1.77	36.4	63.6	64.4	35.6	1.89	30.6	69.4	57.8	42.2
PSR	A1	1.66	35.5	64.5	58.9	41.1	1.78	28.7	71.3	51.1	48.9
	A2	1.68	35.5	64.5	59.6	40.4	1.8	28.6	71.4	51.5	48.5

Soil cone index versus depth

A total of 33 readings of penetrating resistance profiles were recorded, each being average of three measurements. The penetrating resistance profiles for the four sites are shown in [Fig-5] to [Fig-12] A total of thirty-three average profiles were plotted for the four experimental sites. From these observations, the soil layers were classified as upper layer and lower layers, if there is distinct difference in the slopes of the strength profile between the zones. The average penetration resistance of the upper layer and hardpan were tabulated. Also, the depth of occurrence of the hardpan was also recorded.

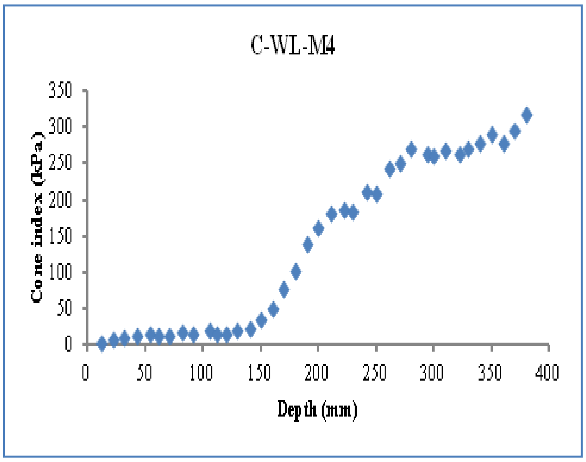

Fig-5 Penetration resistance profile for C-WL-M4

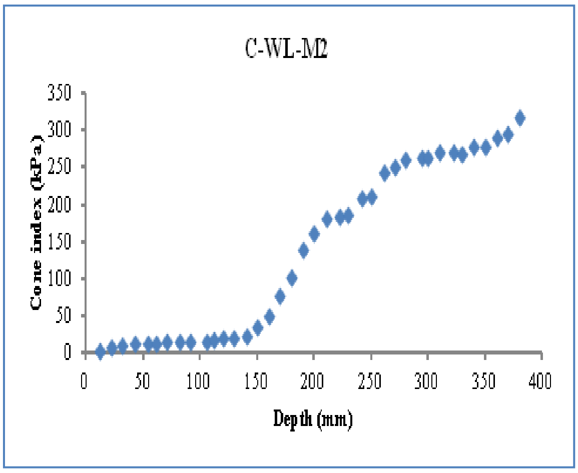

Fig-6 Penetration resistance profile for C-WL-M2

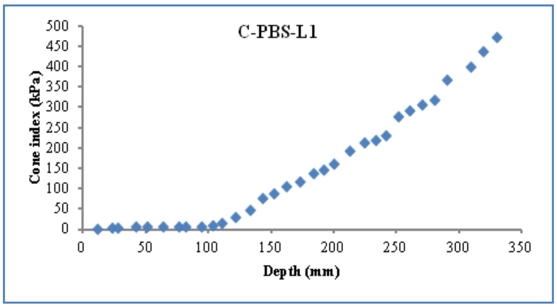

Fig-7 Penetration resistance profile for C-PBS-L1

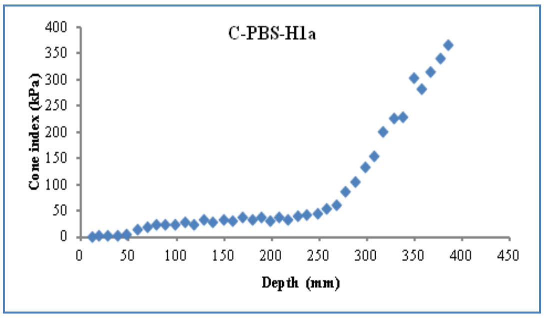

Fig-8 Penetration resistance profile for C-PBS-H1a

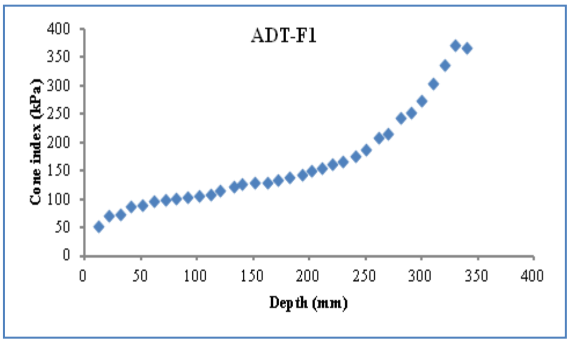

Fig-9 Penetration resistance profile for C-ADT-F1

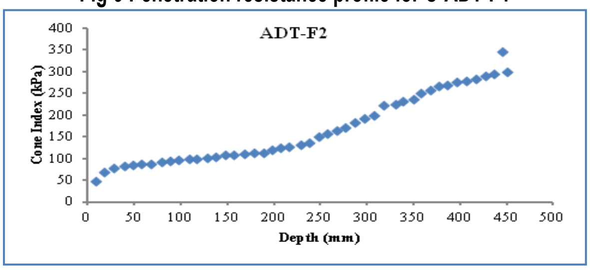

Fig-10 Penetration resistance profile for C-ADT-F2

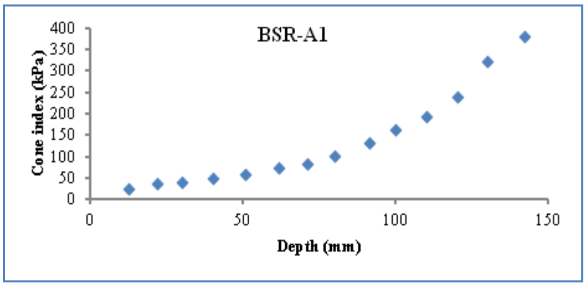

Fig-11 Penetration resistance profile for BSR-A1

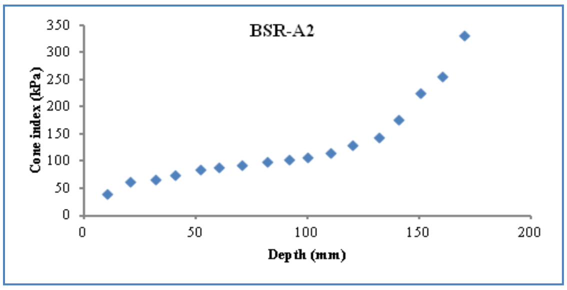

Fig-12 Penetration resistance profile for BSR-A2

Table-4 *Penetration resistance value for experimental field*

Location	Field No.	Cone Index		
		Upper layer (kPa)	Lower layer (kPa)	Single layer (kPa)
C-WL	M4	13.63	159.78	
		15.65	170.75	
		18	187.35	
		23.35	145.03	
		22.04	200.36	
	M2	16.29	185.87	
		19.63	197.26	
		15.65	175.21	
		35.31	177.78	
		22.92	198.42	
C-PBS	H1a	25.97	88.17	
		25.26	131.3	
		21.18	149.21	
		40.59	176.13	
		36.47	139.81	
	L1			153.96
		55.98	200.64	
				174.55
		16.37	181.74	
		6.31	176.27	
ADT	F1			107.66
				140.59
				166.73
	F2	102.33	222.46	
				113.33
		96.16	199.56	
BSR	A1			91.2
				114.64
				105.58
				106.58
				136.05
	A2			169.85
				129.11
				75.91

It was observed that C-WL and C-PBS fields showed a layered soil, while soil strength profiles in BSR and ADT were sigmoid curves, which indicate that the entire soil profile has uniform strength. This type of sigmoid sinkage resistance profile has been observed under laboratory conditions in uniformly compacted soils and sandy soil [7]. The consolidated average penetration resistance values for the upper layer and lower layer for different experimental sites was tabulated in [Table-4].

It was observed that penetration resistance in the upper layer varies between 13.63 and 35 kPa in C-WL and 6.3 and 40.57 kPa in C-PBS sites. Penetration resistance profile in the lower layer varies between 145.03 and 200.36 kPa in C-WL and 88.17 and 200.64 kPa in C-PBS. In case of ADT and BSR sites, the soil strength profile was observed to be uniform and average penetration resistance at 0 to 300 mm depth varied from 67.66 to 166.73 kPa and 75.91 to 169.85 kPa receptively.

In case of C-WL-M2, it was seen that the cone index of lower layer was in order of 10 times the penetration resistance of upper layer. The same trend was observed at C-PBS L1 and H1a sites where distinct difference between upper layer and lower layer could be observed as evident from the cone index of the lower layer which was six times higher than the upper layer.

Conclusion

The physical properties of Soil texture, Moisture content and Bulk density were measured by standard procedure. The texture of four locations varied from sandy clay loam, clay loam, clay and sandy clay loam respectively.

Bulk density varied with depth; and hence samples were taken at two depths of 0 to 10 cm and 10 to 20 cm. Whenever bulk density was measured, measurement of moisture content was also made simultaneously. The moisture content (w.b, per cent) of the lower layer is mostly in the range between 28.6 and 36.9 percentage while moisture content of upper layer was 35.5 to 56.1 percentage. The bulk density of upper layer varied between 1.20 to 1.56 g/cm^3 for the fields at C-WL and C-PBS. However, in the BSR and ADT sites, the bulk density varied between 1.65 and 1.77 g/cm^3. The bulk density in the lower layer varied from 1.52 to 1.72 g/cm^3 for C-WL and C-PBS sites, while for BSR it varied from 1.72 to 1.86 g/cm^3 and from 1.82 to 1.99 g/cm^{3}for ADT.

Moisture content value observed under field condition indicate that except in case of C-PBS, the moisture content in all other fields was approximately 55 per cent in dry basis. This was the condition at the start of the puddling operation in all the experimental sites.

An instrumented electronic hand-held cone penetrometer with a cone base area of 7.8 cm^2 was developed to record the strength of rice soil. The penetration resistance in the upper layer varied from 13.63 to 35 kPa in C-WL and 6.3 to 40.57 kPa in C-PBS. Penetration resistance in the lower layer varied between145.03 and 200.36 kPa in C-WL and 88.17 and 200.64 kPa in C-PBS. In case of ADT and BSR sites, the soil strength profile was observed to be uniform and average penetration resistance in 0 to 30 cm depth varied from 67.66 to 166.73 kPa and 75.91 to 169.85 kPa respectively. The results show the importance of soil physical properties and cone index in predicting tractive properties of tyre working in rice field soil.

Acknowledgement

My sincere thanks to Dr. D. Manohar Jesudas, Professor (FMP) for his continuous encouragement and feeding the knowledge throughout my research work. I also thank, Tamil Nadu Agricultural University, Coimbatore for given opportunity to do this research work.

Application of Research: The main objective of this study is to give a complete picture of soil physical property and cone index. It is also used to as an indicator of soil resistance and provides reference for comparison between different sites. It enables the development of traction models based on penetrating resistance.

Author Contributions: All author equally contributed

Abbreviations:
C-WL: Coimbatore Wetland,
C-PBS- Coimbatore Plant Breeding Station
ADT: Aduthurai
BSR: Bhavanisagar

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