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GEOTECHNICAL EVALUATION OF SOFT SOIL IN MADA REGION: A CASE STUDY FROM KAMPUNG TAJAR, KEDAH

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Graphical abstract

Abstract

Soft soils have emerged as a critical constraint in paddy cultivation within the Muda Agricultural Development Authority (MADA) region, affecting over 8,000 hectares and continuing to expand. Despite recognition of their low strength and high compressibility, limited studies have systematically examined their geotechnical parameters in active paddy fields of Malaysia. This study addresses this gap by assessing moisture content (MC), organic content (OC), maximum dry density (MDD), and optimum moisture content (OMC) of soft soils compared to normal paddy soils. Soil samples were collected from Kampung Tajar, Pendang, Kedah, at two depths (0–20 cm and 20–40 cm) and analyzed in accordance with BS 1377 standards. Results showed that soft soils exhibited consistently higher MC and OC but lower MDD than normal soils, leading to weaker compaction behaviour. Elevated OC was positively associated with MC, while MC showed an inverse relationship with MDD, confirming their causal role in reducing soil strength. These findings highlight the limitations of conventional land preparation and mechanization practices in soft soils. The study provides practical insights for farmers, engineers, and policymakers in designing adaptive soil management and stabilization strategies, and appropriate mechanization practices to enhance paddy productivity and ensure long-term soil sustainability.

Keywords: Soft soil, cone index, MDD, OMC, paddy field

Abstrak

Tanah lembut telah menjadi kekangan yang kritikal dalam penanaman padi di kawasan Lembaga Kemajuan Pertanian Muda (MADA), melibatkan lebih 8,000 hektar dan terus menunjukkan corak peningkatan. Walaupun sifatnya yang berkeupayaan daya galas rendah dan mudah termampat telah dikenalpasti, namun kajian terperinci mengenai parameter geoteknik tanah lembut di kawasan sawah padi Malaysia masih terhad. Kajian ini mengisi jurang tersebut dengan menilai kandungan lembapan (MC), kandungan organik (OC), ketumpatan kering maksimum (MDD), dan kelembapan optimum (OMC) tanah lembut berbanding tanah padi normal. Sampel tanah telah diambil di Kampung Tajar, Pendang, Kedah pada dua kedalaman (0–20 cm dan 20–40 cm) serta dianalisis mengikut piawaian BS 1377. Keputusan menunjukkan tanah lembut mempunyai kandungan MC dan OC yang lebih tinggi secara konsisten tetapi nilai MDD yang lebih rendah berbanding tanah normal, menyebabkan tindak balas pemadatan yang lemah. Kandungan OC yang tinggi menunjukkan hubungan positif dengan MC, manakala MC pula berkorelasi songsang dengan MDD, mengesahkan peranan dalam pengurangan kekuatan tanah. Dapatan ini menyerlahkan keterbatasan amalan penyediaan tanah dan mekanisasi konvensional di kawasan tanah lembut. Kajian ini menawarkan pandangan praktikal kepada petani, jurutera, dan pengubal dasar dalam merangka strategi pengurusan tanah dan penstabilan yang adaptif serta penggunaan mekanisasi bagi meningkatkan produktiviti padi serta memastikan kelestarian tanah dalam jangka panjang.

Kata kunci: Tanah lembut, Kon Indeks, MDD, OMC, sawah padi

1.0 INTRODUCTION

The presence of soft soil in paddy fields, though historically infrequent, has become an increasing concern for farmers due to its impact on agricultural productivity and financial losses. Reports from the Muda Agricultural Development Authority (MADA) indicate significant changes in the extent of affected areas over the years. In 2012, MADA identified 6,230 hectares of problematic land, with 860 hectares classified as soft soil and the remaining areas categorized as potentially soft soil. By 2013, the affected region expanded to 2,853 hectares, while the area classified as potentially problematic declined marginally to 16 hectares. However, in 2016, a substantial reduction was recorded, with only 83 hectares affected, suggesting temporary stabilization. Notably, by 2022, the impacted area surged to 2,724 hectares, indicating a possible recurrence of the issue [1]

The engineering characteristics of soft soil are highly complex and influenced by multiple factors, including mineralogical composition, chemical properties, and interparticle interactions [2]. These soils exhibit low mechanical strength, high compressibility, and reduced bearing capacity, which adversely affect their suitability for agricultural activities [3], [4]. From an agricultural engineering perspective, soft soil in paddy fields is defined as a soil type lacking a dense sublayer, making it incapable of supporting mechanized farming operations. This classification is often associated with an index cone reading of less than 0.3 MPa, as measured by a penetrologger [5], [6]

Several studies have examined the physical and mechanical properties of soft soil, emphasizing the role of water content and bulk density in soil strength development [7]. Empirical findings suggest that bulk density values for soft soil range from 1.002 to 1.008 g/cm³, while aggregate stability is approximately 17%. The low-density structure indicates an absence of compacted soil particles, leading to increased porosity and weak interparticle bonding. Consequently, such soils are prone to disintegration and brittleness upon drying.

The classification of soft soil is commonly determined through index cone penetration tests, performed at 30 cm depth, and categorized into three groups: soft soil, workable soil, and soil suitable for cultivation [8], [9]. The index cone method, developed through collaborative research by MARDI and the Department of Agriculture, has been refined using advanced soil classification technologies under the 11th Malaysia Plan [1]. Moisture content (MC) and organic content (OC) regulate soil compressibility, water retention, and fertility, while optimum moisture content (OMC) and maximum dry density (MDD) govern compaction efficiency and load-bearing capacity—parameters that are critical for effective land preparation and mechanization in paddy fields. Despite recognition of soft soil limitations, few studies have systematically compared MC, OC, OMC, and MDD between soft and normal paddy soils in Malaysia, leaving their implications for mechanization and land management poorly understood. This knowledge gap poses a direct challenge to sustainable rice cultivation, as inadequate soil management on soft soils leads to reduced productivity, increased operational costs, and long-term soil degradation in the MADA region.

Despite substantial advancements in understanding soft soil behavior, the fundamental mechanisms underlying its formation and classification remain ambiguous. This study seeks to address this knowledge gap by conducting a comprehensive analysis of key soil properties, potentially serving as indicators of soft soil in paddy fields. The findings are expected to provide practical insights for farmers, researchers, and policymakers in mitigating the impact of soft soil, thereby enhancing agricultural sustainability and productivity.

2.0 METHODOLOGY

The soil sampling process was conducted in two designated field plots located in Kampung Tajar, Kedah, Malaysia, with geographical coordinates N 6°04'58.4", E 100°24'56.2" (Figure 1). One plot was allocated for the analysis of normal soil, while the other was designated for soft soil assessment. The size of each study plot ranged between 0.6 and 0.9 hectares, ensuring a representative sampling area for comparative analysis.

Figure 1 Research plot at Tajar, Kedah (photo from Google Earth)

A total of five sampling points were systematically selected within each plot to capture spatial variability. The sampling points in the soft soil plot were labeled A, B, C, D, and E, while those in the normal soil plot were identified as P, Q, R, S, and T were selected based on prior field surveys and index cone readings to ensure representative conditions of soft and normal soils. (Figure 2). To examine vertical soil variations, samples were collected at two depths: 0–20 cm and 20–40 cm below the soil surface. In total, 20 samples were collected and analyzed.

Sampling was carried out in March 2024, during the main paddy cropping season, under controlled irrigation managed by MADA. Fields were maintained at a water depth of approximately 5–10 cm, consistent with standard irrigation practices. Soil collection was undertaken two weeks after transplanting, ensuring that samples reflected the active cultivation stage.

All samples were carefully prepared in accordance with BS 1377 (1990): Part 2, 1990 clause 3.2 for Moisture Content, ASTM D7348-08 for Loss on Ignition [10], and BS 1377: Part 4: 1990 clause 3.1 for the Compaction Test [11], [12], with roots and coarse organic materials removed to minimize disturbance. Soil texture was determined using hydrometer analysis, and classification was conducted using the Unified Soil Classification System (USCS). Compaction tests were performed on representative samples from the soft soil plots (A, C, and D), which exhibited the lowest index cone values (<0.3 MPa), to capture critical conditions for mechanization and land preparation.

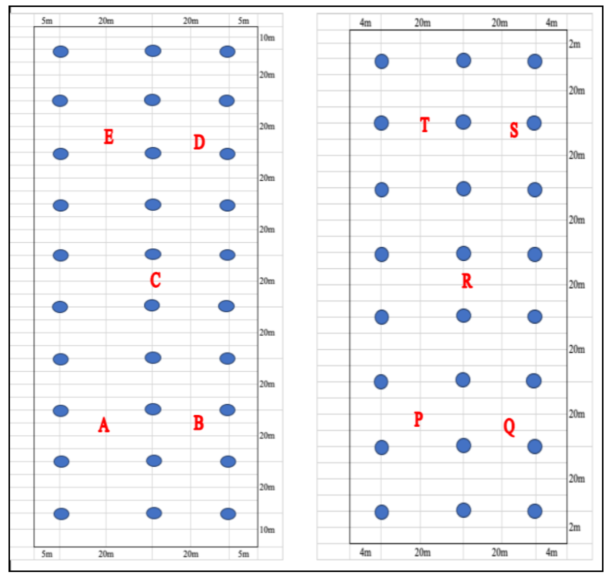

Figure 2 Schematic layout for data collection and soil sampling in soft soil plots (A–E) and normal plots (P–T)

Figure 3 presents a visual comparison between the normal paddy plot and the soft soil plot, highlighting the distinct differences in surface stability, soil structure, and field operability. The normal plot demonstrates firmer ground conditions suitable for mechanized operations, while the soft soil plot exhibits signs of subsidence, high water retention, and poor trafficability, which can severely impede machinery movement and affect crop management efficiency.

Figure 4 shows a comparative aerial view of several paddy plots located within the same agricultural zone. Notably, the central and right-side plots illustrate the characteristics of soft soil areas, with evident surface water accumulation, irregular vegetation growth, and disrupted field patterns. These plots exhibit excessive ponding, vegetation intrusion, and indistinct tillage marks, all of which are indicative of low bearing capacity, poor drainage, and soil settlement issues, commonly associated with soft or problematic soils.

(a) Normal plot

(b) Soft soil plot

Figure 3 Physical condition comparison (a) normal paddy field (b) soft soil area

In contrast, the surrounding plots, particularly on the top left, appear more uniform with clear tillage lines and minimal surface water retention, suggesting better ground firmness and trafficability, typical of normal soil conditions. The visible degradation in field operability in the soft soil areas underscores the challenges faced in mechanized operations and crop uniformity, which can lead to reduced productivity and higher maintenance costs. This contrast highlights the necessity for soil stabilization interventions in affected zones to ensure sustainable rice production.

Figure 4 Aerial photo highlighting differences in surface condition, water retention, and field operability

3.0 RESULTS AND DISCUSSION

Based on classification from U.S. Department of Agriculture (USDA), the soils from the study area exhibit uniform characteristics, predominantly classified as silty clay, with silt and clay fractions ranging between 45–55%. In contrast, the coarse and fine sand components were minimal, identified within the range of 0.1–0.5%, as presented in Table 1. A comparison with previously collected samples revealed highly consistent results, confirming the fine-grained and cohesive nature of the soils.

Table 1 Results of Particle Size Distribution

Plot Condition	Depth (cm)	*Percentage (%)* Coarse	Fine	Silt	Clay
Soft Soil	20	0.27	0.17	48.32	51.25
	40	0.40	0.10	44.42	55.08
Normal Soil	20	0.46	0.10	50.26	49.16
	40	0.22	0.16	47.56	52.06

*Note: ($p<0.05$, $n=20$)

(a) Soil Moisture Content

A two-way ANOVA revealed a significant main effect of soil condition on moisture content [$F(1,56)=10.757$, $p=0.002$], with soft soil exhibiting higher values than normal soil. There was also a significant main effect of depth [$F(1,56)=16.388$, $p=0.001$], where moisture content was consistently higher at 20 cm than at 40 cm. A significant interaction between soil condition and depth [$F(1,56)=4.269$, $p=0.043$] indicated that the magnitude of depth-related differences varied by soil type.

The average moisture content in soft soil was 65.18% at 20 cm and 58.46% at 40 cm, whereas normal soil recorded 61.07% and 40.37% at the same respective depths (Table 2). The depth-related difference (Δ) was smaller in soft soil (6.72%) than in normal soil (20.7%), suggesting stronger vertical stratification of moisture in normal soil. This pattern indicates that in soft soil, moisture content fails to decrease substantially with depth, remaining at high levels up to 40 cm.

This persistence of elevated moisture suggests poor drainage and limited downward percolation, which can prolong water retention and contribute to soil instability. Such conditions may reduce effective stress, weaken soil structure, and exacerbate settlement issues commonly observed in saturated clayey paddy soils [7]. In contrast, the normal soil plot exhibited more efficient drainage, allowing percolation and surface runoff to prevent excessive moisture accumulation in the subsoil. The standard deviation values were relatively consistent across depths and soil conditions, indicating low variability and a stable moisture distribution pattern within each soil type.

In rice cultivation, [13] (refer to Table 3) suggests that the optimal soil moisture content should remain below 40% for optimal growth conditions. However, previous studies by [7], [14] reported moisture content values exceeding 40%, raising concerns regarding soil density and water retention capacity. Reported moisture content values ranged from 46% to 75%, highlighting a potential issue linked to low soil density and poor compaction properties.

Table 2 Results of *In-Situ* Moisture Content

Plot Condition	*In situ* Moisture Content (%)	
	20 cm	**40 cm**
Soft Soil	47.52 - 73.20 Range (46 – 75) Avg (65.18) Std (9.04)	46.43 – 71.67 Range (46 – 75) Avg (58.46) Std (8.93)
Normal Soil	51.88 – 69.87 Range (50 – 70) Avg (61.07) Std (7.08)	36.08 – 56.38 Range (35 – 60) Avg (40.37) Std (8.07)

*Note: Avg- Average, Std – Standard Deviation

Studies have reported that soft soils exhibit high porosity, which facilitates water infiltration and retention within the void spaces between soil particles. This characteristic significantly influences the soil's hydraulic behaviour, leading to increased compressibility and reduced shear strength [15], [16]. The high void ratio in soft soils allows water to occupy the interparticle spaces, affecting the bonding mechanisms and overall structural integrity [3].

Several factors contribute to excessive soil moisture, including high soil capillarity, increased void ratio, soil texture composition, and water-holding capacity [17]. Additionally, poor permeability and environmental influences such as climate variability, groundwater fluctuations, and agricultural practices further exacerbate moisture retention. Collectively, these findings demonstrate that both soil condition and depth significantly influence soil moisture distribution and that their effects are interdependent. The persistently high moisture content observed in soft soils reflects their poor drainage and high water-holding capacity, which adversely affect their geotechnical performance and complicate water management in paddy field systems

Table 3 Comparison of Normal and Soft Paddy Soil Properties

Soil Properties	Normal Paddy Soil[13]	Soft Paddy Soil[7,14]
pH	5.5 – 6.5	3.2
Density(gcm^{-3})	> 1.0	≤1.0
Moisture content (%)	< 40	> 50
Organic carbon content (%)	2 -3	0.67
Soil Hydraulic Conductivity, cm h $^{-1}$	0.5	0.19

(b) Organic Matter Content

The determination of soil organic matter content (%) through Loss on Ignition (LOI), as outlined by [18], [19], revealed notable differences between soft soil and normal plots, as presented in Table 4. Organic matter plays a crucial role in soil behavior, particularly in soft soils where it influences compressibility, shear strength, and settlement characteristics [16], [20]. Generally, the organic content for soft soil was 9.5 percent and above, based on the average value gathered, and the normal soil was below 9.5 percent. The quantification of organic matter was conducted in two distinct phases: before planting (BP) and during planting (DP). These measurements aimed to reconfirm the organic content in both normal and soft soil conditions.

A two-way ANOVA revealed a significant main effect of soil condition on organic content [F (1,16) =7.707, p=0.010], indicating that soft soil contained higher organic matter than normal soil. However, the main effect of depth [F (1,16) =1.954, p=0.181] and the interaction between soil condition and depth [F (1,16) =0.197, p=0.663] were not significant. These results suggest that organic matter distribution was primarily influenced by soil type/condition rather than depth, consistent with the accumulation of organic residues in soft soils and the mixing effects of tillage that homogenize organic matter across depths.

Table 4 Organic Content at 20 cm and 40 cm

Plot Condition	Organic Matter Content (%)			
	20 cm		**40cm**	
	BP	**DP**	**BP**	**DP**
Soft Soil	Avg (10.67) Std (1.17)	Avg (11.27) Std (1.47)	Avg (10.16) Std (1.46)	Avg (9.86) Std (1.05)
Normal Soil	Avg (9.40) Std (0.88)	Avg (8.98) Std (0.32)	Avg (8.37) Std (0.81)	Avg (7.93) Std (0.66)

**Notes*: Avg- Average, Std- Standard Deviation

The average value of BP was greater than DP except for the depth of 20 cm for soft soil. The value decreased after planting due to plant uptake in the normal soil. The microbes and the soil nutrients were absorbed by the paddy. A different trend was observed in the soft soil at 20 cm depth, where waterlogging created anaerobic conditions and the organic content continued to increase. This disparity indicates a significant concentration of organic matter in the soft soil plots, a factor that could influence soil characteristics. The presence of higher organic content in soft soil plots implies a potential susceptibility to compaction, as noted by [21]. Conversely, normal plots were found to have a smaller proportion of organic matter, suggesting a difference in soil structure between the two conditions. Reference [22] highlights that the presence of organic matter can lead to a reduction in soil bulk density. This phenomenon is attributed to the simultaneous increase in the amount of organic matter and the proportion of voids within the soil.

Furthermore, the continuous waterlogging of paddy fields can lead to the formation of anaerobic conditions, which might hinder the decomposition of organic materials. This limitation might cause a progressive development of organic matter over time, resulting in an overall rise in the organic content of the soil. These conditions impede the usual decomposition processes, resulting in the persistence of organic matter and an increase in the soil's organic content levels. The accumulation of plant and animal residues in the soil contributes to increased organic content. The decomposition of organic matter from previous plant growth, crop residues, and other biological materials enriches the soil with organic substances. The management of crop residues, such as rice straw, by farmers plays a pivotal role in influencing organic content. Incorporating residues into the soil, as opposed to their removal, tends to result in higher organic content. Therefore, understanding and managing organic matter levels are crucial considerations in soil management practices for sustainable agriculture.

(c) Optimum Moisture Content with Maximum Dry Density

The compaction test results, as illustrated in Figure 5, revealed that the Optimum Moisture Content (OMC) for the selected soft soil samples (A, C, and D) ranged between 25.0% and 32.5%, with an average value of 28.5%. In contrast, the OMC of the normal soil samples (P, Q, and T) was found to range from 19.5% to 27.7%, with an average of 25.0%. This disparity highlights the higher moisture retention capacity of soft soils, which can significantly influence their engineering behavior and long-term stability. Prolonged moisture retention in soft soils tends to weaken the soil matrix, reduce shear strength, and decrease the overall bearing capacity. These geotechnical deficiencies may lead to structural instability, especially under repeated loading or seasonal saturation. In agricultural contexts such as paddy fields, excessive water retention may also cause waterlogging, adversely affecting crop health by impeding root respiration and nutrient absorption [23].

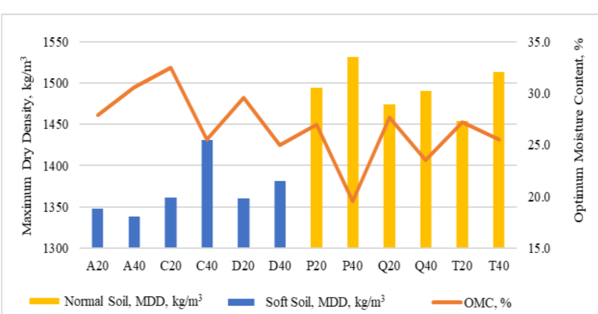

Figure 5 Results of Compaction Test

A two-way ANOVA revealed a significant main effect of soil condition on optimum moisture content (OMC) [$F(1,8) = 5.835$, $p = 0.042$], with soft soil exhibiting higher OMC values than normal soil. Similarly, there was a significant main effect of depth [$F(1,8) = 6.772$, $p = 0.032$] indicating that OMC varies with soil depth. However, the interaction between soil condition and depth was not significant [$F(1,8) = 0.276$, $p = 0.614$]. These results suggest that both soil condition and depth independently influenced the OMC, but their combined effect was negligible.

The elevated OMC observed in soft soils is largely attributable to their geotechnical and mineralogical composition. Soils in paddy field areas typically contain a high proportion of fine-grained clay particles and organic matter, both of which enhance the soil's ability to retain moisture over extended periods [15]. The fine particles provide a larger specific surface area, enabling greater water adhesion and retention capacity [14], [24]. Furthermore, the presence of expansive clay minerals such as montmorillonite and kaolinite significantly contributes to water absorption due to their swelling and shrinkage properties [14]. These findings underline the necessity of implementing appropriate soil management strategies to mitigate the adverse impacts of excessive moisture in soft soils. Techniques such as the installation of efficient subsurface drainage systems and soil stabilization using chemical additives have shown promising results. The application of soil amendments, including lime or cement, has been widely documented to improve soil structure, reduce plasticity, and lower moisture retention [25]. Hence, a thorough understanding of OMC variation between soft and normal soils is crucial for effective land use planning and the development of sustainable agricultural and infrastructural practices.

In addition to OMC, the Maximum Dry Density (MDD) provides essential insight into the compactness and mechanical behaviour of soils. The MDD of soft soil samples ranged from 1338 kg/m³ to 1361 kg/m³, with a mean value of 1350 ± 30 kg/m³. In comparison, the normal soil samples exhibited MDD values between 1474 kg/m³ and 1531 kg/m³, with an average of 1500 ± 30 kg/m³.

A two-way ANOVA revealed a significant main effect of soil condition on maximum dry density (MDD) [$F(1,8) = 59.426$, $p < 0.001$], with normal soil exhibiting higher MDD values than soft soil. However, the main effect of depth was not statistically significant [$F(1,8) = 4.053$, $p = 0.079$], and the interaction between soil condition and depth was also not significant [$F(1,8) = 0.105$, $p = 0.755$]. These results suggest that soil condition exerted a dominant influence on MDD, while depth had only a minor, non-significant effect, and there was no combined effect between the two factors. The higher MDD observed in normal soil likely reflects its denser mineral structure and lower organic matter content, which enhance particle packing and compaction efficiency, whereas the lower MDD in soft soil may be attributed to its higher water content and organic matter, which reduce soil particle contact and load-bearing capacity.

The comparatively lower MDD of soft soils can be attributed to their high moisture content, fine particle size distribution, and plasticity, which limit the soil's ability to achieve dense packing under compactive effort. On the other hand, normal soils with coarser texture and lower water content facilitate closer particle arrangement during compaction, resulting in higher dry densities. These observations are consistent with previous studies that have reported reduced MDD values in highly plastic clays due to increased water film thickness and inter-particle repulsion during compaction [24].

The distinct difference in MDD between soft and normal soils reinforces the need for careful assessment during land preparation, particularly in areas underlain by soft clay deposits. Soil improvement techniques, such as preloading, vertical drains, and chemical stabilization, may be necessary to enhance the load-bearing performance and stability of these problematic soils.

The correlations between soil parameters were examined using the Pearson product-moment correlation coefficient. There was a very strong positive correlation between soil condition and maximum dry density ($r = 0.911$, $p < 0.01$), suggesting that normal soils had substantially higher MDD than soft soils. Soil condition also showed significant negative correlations with organic content BP ($r = -0.627$, $p < 0.05$) and organic content DP ($r = -0.616$, $p < 0.05$), indicating that soft soils contained higher organic matter than normal soils.

Moisture content was strongly positively correlated with both organic content BP ($r = 0.666$, $p < 0.05$) and organic content DP ($r = 0.666$, $p < 0.05$), as well as with optimum moisture content ($r = 0.722$, $p < 0.01$). This pattern indicates that soils with higher organic matter also tend to retain more water and require higher moisture to achieve maximum compaction.

Organic content BP and DP were very strongly positively correlated ($r = 0.938$, $p < 0.01$), confirming consistency between the two organic content measurements. In contrast, maximum dry density showed strong negative correlations with organic content BP ($r = -0.794$, $p < 0.01$), organic content DP ($r = -0.756$, $p < 0.01$), and optimum moisture content ($r = -0.727$, $p < 0.01$). This suggests that soils with higher organic matter and higher water demand tend to have lower compaction capacity due to reduced particle contact and increased pore spaces.

No significant correlations were observed between depth and the other parameters, implying that vertical variation within the tested range (20–40 cm) had minimal influence compared to the differences between soft and normal soil conditions.

Overall, the Two-way ANOVA confirmed that differences in moisture content (MC), organic content (OC), optimum moisture content (OMC), and maximum dry density (MDD) between soft and normal soils were statistically significant ($p < 0.05$). The Pearson product-moment correlation coefficient analysis further revealed distinct relationships among these soil properties. OC was positively correlated with MC ($r \approx 0.72$, $p < 0.01$), indicating that soils with higher organic matter tend to retain more water. Similar findings have been reported by [27], who observed that organic matter enhances the soil's water-holding capacity through increased porosity and hydrophilicity. In contrast, MC showed a negative correlation with MDD ($r \approx -0.68$, $p < 0.01$), suggesting that increased soil moisture—largely influenced by organic matter—reduces soil particle packing efficiency, thereby lowering dry density. This inverse relationship is consistent with the observations of [21]and [28], who reported that organic-rich soils exhibit lower compaction capacity and higher compressibility due to their lower particle density and weaker interparticle bonding. Collectively, these findings imply that organic-rich soils retain more water but achieve lower compaction, which contributes to their lower load-bearing capacity compared to mineral-dominated soils.

As shown in Table 5, the results revealed that soft soils exhibited consistently higher moisture levels than normal soils at both 20 cm and 40 cm depths. The combined influence of excessive moisture, high organic content, and low compaction characteristics reinforces the need for integrated soil management strategies to ensure sustainable agricultural and infrastructural development on soft ground.

Table 5 Results of Soft and Normal Soil

Paddy Condition	Depth (cm)	*In situ* MC (%)	Organic Content (%)	OMC (%)	MDD (kg/m³)
Soft Soil	0 – 20	65.18	10.98	30.0	1357
	20 -40	58.46	10.01	27.0	1383
Normal Soil	0 – 20	61.07	9.19	27.3	1474
	20 - 40	40.37	8.15	22.9	1512

4.0 CONCLUSION

This study has demonstrated clear distinctions between soft soil and normal soil in terms of moisture content, organic content composition, and compaction behaviour. The findings revealed that soft soil retained significantly higher moisture content across both surface and subsurface layers, with values exceeding 58% even at a depth of 40 cm. In contrast, normal soil exhibited a sharper decline in moisture with depth, indicating better drainage and water percolation. This prolonged moisture retention in soft soils indicates low permeability, poor drainage capacity, and a high risk of waterlogging, which could negatively impact an agricultural productivity, especially in water-sensitive environments like paddy fields.

This condition, combined with a fine-grained texture and the presence of expansive clay minerals, contributed to increased water retention, low shear strength, and high compressibility. These geotechnical properties highlight the inherent limitations of soft soils for agricultural use without prior treatment. Therefore, the implementation of proper soil improvement techniques such as s surface and subsurface drainage, soil replacement, chemical stabilization, and moisture control is essential to enhance the physical behaviour of soft soils. Understanding these differences is critical to ensuring safe, stable, and sustainable land preparation practices on soft ground.

The complex interaction of these factors highlights the need for effective soil management strategies, particularly in drainage improvement and moisture regulation. Addressing these challenges is essential to mitigate soft soil issues, enhance soil stability, and promote sustainable rice production in affected regions. Future research should evaluate stabilization treatments and long-term monitoring of soil behaviour under different mechanization systems to inform sustainable land management strategies

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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