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Multi Criteria Approach to Determine the Suitability of Application of Motorcycle Drawn Potato Harvesters

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ABSTRACT

Agricultural mechanisation is vital because it raises labour efficiency and enhances farm production per worker. However, not all fields are suitable for mechanisation. This study sought to determine the viability of introducing potato harvesting equipment drawn by motorcycles in Nyandarua County, Kenya. Soil analysis was done on samples from different parts of the county to understand the properties of soils that affect agricultural tool interaction and to study the movement of the digging part of the machines in the soil. With the help of various physical and mechanical soil tests, this study spatially determined suitable areas for potato mechanisation using Multi-Criteria Evaluation and Geographic Information System analysis. The criteria used in this analysis were soil, climate, and topography. The criteria were selected based on information available about potato mechanisation. The data from the criteria was analysed in the Quantum Geographic Information System environment. A map was generated in which the area was classified into four suitability levels for the operation of a potato harvester: Highly Suitable (S1), Moderately Suitable (S2), Marginally Suitable (S3), and Not Suitable (N) based on Food and Agriculture Organization guidelines. The Analytic Hierarchy Process decision-making tool was used to determine each criterion's deduced weights and associated influence. The weights were used as inputs in the weighted overlay analysis and final maps generated. This research aids in informed decision-making for agricultural mechanization in Nyandarua County, helping farmers and policymakers identify the most suitable regions for adopting this technology. By enhancing labour efficiency and farm productivity, the findings contribute to the overall improvement of the agricultural sector in the region, emphasizing the importance of considering multiple criteria when assessing the feasibility of introducing new farming equipment.

Keywords: Agricultural mechanization, Tool interaction, Physical-mechanical soil tests, post-harvest losses.

Highlights of the Study

- The development of a motorcycle-based potato harvester was made to enhance efficiency and decrease labor in small-scale farming.
- Analyzed soil properties, drainage, depth, and other factors to assess land suitability for mechanized potato harvesting.
- Found that Nyandarua County has a significant portion of land highly suitable for potato mechanization.
- Identified the critical importance of soil drainage and texture in determining suitability for mechanization.

INTRODUCTION

Background Information

The research project focussed on developing a potato harvester for small-scale farmers with a motorcycle as a prime mover. According to Li et al. (2020), potato harvesting is the most labour-intensive and time-consuming activity in potato production. It was also envisaged that using a potato harvester would reduce post-harvest losses.

This arrangement also takes advantage of the recent exponential increase in the number of motorcycles in the country to act as intermediate and affordable prime mover between human power and tractors. Introducing a motorcycle potato harvester can significantly improve worker efficiency and increase potato production per worker. In a manual scenario, workers would manually dig up potatoes from the ground using tools like shovels or hand forks. However, introducing a motorcycle potato harvester eliminates the need for manual labour-intensive digging, reducing the physical effort required from workers. This increases efficiency, allowing workers to focus on operating the machine and maintaining a steady workflow, (Abdelrahman et al,2022 and FAO 2014c).

The motorcycle potato harvester can dig up potatoes faster than manual digging, covering a larger area in a shorter time and maximising productivity for each worker. Additionally, the machine's conveyor system allows for continuous collection and storage of harvested potatoes, eliminating the need for manual collection and transport, further increasing production per worker. Wei et al. (2019) remarks that introducing a motorcycle potato harvester improves labour efficiency by reducing physical exertion and increasing potato production per worker by enabling faster and more effective harvesting.

The introduction of the motorcycle potato harvester, can benefit various stakeholders, including farmers, agricultural machinery manufacturers, policymakers, and agricultural organisations. The motorcycle potato harvester can reduce labour costs and farmers can benefit from increased efficiency, productivity, market demand, innovation, save time, and allow farmers to allocate their time and resources to other essential farm activities. Agricultural machinery manufacturers can identify market opportunities, develop innovative designs, and optimise the harvester's performance to meet farmers' specific needs. Policymakers and agricultural organisations can use the research outputs to develop policies that encourage the adoption of agricultural mechanisation, enhancing agricultural productivity, improving rural livelihoods, and contributing to food security. Overall, the research outputs will provide valuable information for stakeholders to make informed decisions and optimise their potato production.

The motorcycle potato harvester used in the project is a versatile tool designed to harvest potatoes efficiently and effectively. It includes a sturdy frame, mounting provisions, a digging and lifting mechanism, a collection and separation system, cleaning and sorting components, a power and control system, mobility and manoeuvrability, dimensions and capacity, and maintenance and accessibility. The specifications, dimensions, and performance parameters of a motorcycle potato harvester depend on the desired scale of operation, soil conditions, available power source, and budget. Detailed engineering design, prototyping, and testing have been affected to develop a fully functional and efficient machine.

Other factors, such as soil structure, organic matter content, fertility, and compaction, also influence the suitability and success of potato mechanisation (Hrushetskiy & Yaropud, 2020a). Wang et al. (2022) encourages that local conditions and agronomic practices should be considered when deciding land preparation, machinery selection, and soil management techniques for efficient and effective potato cultivation and mechanised harvesting.

Motorcycles were selected as the prime movers due to their availability in large numbers in the country, affordability and ease of operation. There are many trained motorcycle riders in the country. This paper focuses on the soil properties pertinent to soil–tool interaction for potato harvester design and fabrication purposes. The data was collected spatially across the county and merged with other critical physical factors in GIS to make suitability maps.

This study investigated and evaluated the effect of soil and topography on the potential of a motorcycle potato harvester as an effective and efficient tool for potato harvesting.

Soil Classification

This is important because harvesting machines interact with the soil during operation. The working body of the digging machine develops the soil and removes it from the bottom. Thus, the properties of soils are of significant interest when considering questions of their development and agricultural tool interaction, as well as studying the movement of the digging part of the machines on the surface of the soil. Soils consisting of solid and gaseous phases are rare in natural conditions (Hrushetskiy & Yaropud, 2020b).

The properties of each phase, the quantitative relationships, and the interaction between them determine the soil's specific physical and chemical nature and its agricultural production properties. Hrushetskyi et al. (2019) comments that to assess the phase composition of soils, characteristics are used that express quantitative relations between the volumes of solid mineral particles, water and gas. The strength characteristics of soils largely depend on the composition of the soil, i.e., from the relative content of particles of various sizes in it, as well as from its density and humidity.

Nyandarua County has four soil texture classes summarized:

1. Loamy soils with significant cohesion when dry but lose it when wet are classified as "Clay" or "Silt" (as per Soil Taxonomy) depending on particle size distribution. They can also be classified as "Vertisols"(as per World Reference Base) due to their high clay content and shrinking and swelling properties.
2. Very clayey soils, classified in Soil Taxonomy and the World Reference Base for Soil Resources, are highly weathered, less weathered, cold, humid, luviated, gleysol, and Andosol, with varying clay content and volcanic ash content.
3. Loamy clay soils with great cohesion, density, and ductility are classified as "Clay" or "Well-Drained Clay" (as per Soil Taxonomy) if they have good drainage. They share characteristics with "Vertisols," (as per World Reference Base) clay-rich soils known for their shrinking and swelling behaviour though these soils can be classified under various categories.
4. Sandy soils with high internal friction, good permeability, and resistance to wetness are classified as "Sand" and "Well-Drained Sand"(as per Soil Taxonomy) if they have good drainage properties. They are also known as "Arenosols" (as per World Reference Base) due to their sand dominance and excellent drainage properties.

The movement of vehicles and machinery on loose sand is challenging. Both loam and sandy clay are suitable for potato harvesters.

Land Suitability Analysis

The Land Suitability Analysis (LSA), a GIS-based process, is used to assess an area's suitability for its intended use, whether or not it is acceptable given its inherent qualities (Kumawat & Raheman, 2022). Land suitability is defined by (AbdelRahman et al 2022) as the aptitude or competency of a specific type of land for a specified application. The land can be viewed as it is now or after improvements. The evaluation and classification of specific land parcels according to their appropriateness for predetermined applications is the land suitability classification process (Zhou et al., 2021). The following list of land suitability classes is based on (AbdelRahman et al, 2022):

- Class S1 – Highly Suitable (No significant limitations)
- Class S2 – Moderately Suitable (Moderate limitations)
- Class S3 – Marginally Suitable (Severe limitations for sustained applications)
- Class N1 – Currently not Suitable (Surmountable limitations)
- Class N2 – Permanently not Suitable (Severe limitations)

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MATERIALS AND METHODS

Soil Testing

Disturbed and undisturbed soil samples were collected and air-dried for laboratory tests. The soil color was determined using Revised Standard Soil Color Charts ((Hrushetskiy & Yaropud, 2021).

In-situ Soil Tests:

The following in-situ soil tests were conducted: Cone Penetration Test, Shear Properties Test (Shear Strength and Angle of Internal Friction), Permeability Test (Falling Head Method), Soil

Colour, Sieve Analysis, Bulk Density, Triaxial Test, Atterberg Limits and Soil Texture (Bouyoucos Method).

Suitability Analysis
The spatial data determination was carried out in the following process:

Spatial and Non-Spatial Data:
An area is described through spatial data. Graphic primitives, such as points, lines, spot heights, polygons, or pixels, are how they are represented. Data that is not spatial refers to a specific, clearly defined location. They may also be referred to as characteristic or attribute data. Information that is not based on any geometrical factors is known as non-spatial data. The GIS then connects these to the spatial data that pinpoints the place.

Geodatabase:
A geodatabase is an alternative method for storing GIS data in a single, sizable file that contains numerous points, polylines, or polygons. It is intended to be used to store, retrieve, and work with spatial and geographic data. Also referred as spatial database.

Pre-processing and Classification of Datasets in QGIS:
Pre-processing shapes the datasets you place in the GIS i.e., it prepares them for analysis. On a map, classification is the practice of designating members of a group by the same symbol, typically stated in a legend. Classification is the act of grouping or categorizing elements into groups or categories.

Normalization, Standardization and Reclassification of Data:
Data normalization is a methodical process for ensuring that a database structure is acceptable for all types of queries and devoid of some undesired features that could result in a loss of data integrity. Data standardization is the process of putting data into a format that is widely used so that users may process and **analyse** it. The process of redesignating a value, a range of values, or a list of values in a raster to new output values is known as data reclassification.

Weighting using AHP (Analytical Hierarchy Process) and MCDM (Multi-Criteria Decision Analysis):
In a pairwise comparison matrix, which is a measure to indicate the relative preference among the factors, all factors considered essential for a decision are compared to one another (Belton and Stewart, 2001). The Analytic Hierarchy Process involves three essential steps: factor selection, pairwise evaluation of important factors, and weight generation.

Using the scale, preference intensities are indicated as equal significance, equally to moderate, moderate to strong, vital to extreme, very strong to exceedingly, and extreme importance, respectively, using the numbers 1, 2, 3, 5, 6, 7, 8, and 9. (Wei et al., 2019b). The consistency was examined by determining the consistency ratio (CR). According to Alonso et al, 2006), pairwise comparisons must be consistent if the CR is less than 0.1.

Weighted Overlay:
This entailed taking several datasets, comparing a single cell across all of them to determine if it met particular criteria, assigning it a weight if it did, comparing them, and giving them a final score that could aid in understanding the interactions between these various datasets.

Final Soil Mechanization Suitability Map:
After assessing and reclassifying the criteria maps, each one was given a specific % weight that will be decided by specialists based on its impact on potato mechanization. Analytical Hierarchy Process was used to obtain these maps. The maps were then superimposed to create the soil mechanization suitability map, which is the result.

RESULTS AND DISCUSSION

This section shows the outcomes of laboratory soil testing, the regional variance of each sub-criteria for potato mechanization suitability classes, and the outcomes of the AHP, MCE technique for determining the suitability of the land.

Soil Analysis
Permeability Test:
From the values of saturated hydraulic conductivity (K_{sat}) as presented in Table 1, it was determined that loam soil, Loam- clay soil and Clay soil are well drained and therefore better for the potato harvester mechanization compared to sandy soils because of lower maximum saturated hydraulic conductivity (K_{sat}).

Table1: The K_{sat} of different soils in Nyandarua (County Calculated Data)

Soil type	K_{sat} Range (cm/hr)	Conductivity class
Loamy soil	0.8- 80	moderate to very rapid
Loam clayey soil	0.4 - 70	slow to rapid
Clayey soil	0.3- 115	Very slow to moderate
Sandy soil	0.5-32	rapid to very rapid

Cone Penetration Test:
The cone penetration resistance of cultivated land was 2 to 4.3 Kg/f, recently in use land was from 4.6 to 9.2 Kg/f and fallow land ranged from 5.6 to 10 Kg/f (where 1Kgf is equivalent to 9.806650N0. Fallow land in the county had the greatest cone penetration resistance due to the natural compaction of the soil. For most of the soils, the resistance increased with depth. Loamy soils registered the least cone penetration registered on average, while Sandy and Clayey soils registered the highest resistance on average. This indicated that Nyandarua county soils are suitable for potato mechanisation since its characterised by loamy soils that has least cone penetration as outlined by Lunne at al 1997.

Table 2: Cone Penetration Test (CPT) Ranges of the Soil Samples

Suitability class	Soil texture	Area (ha)	Cone penetration range
S1	Loamy	45,965	Moderate Soft to Firm
S2	Loam Clayey	189,882	Moderately stiff
S3	Clayey	74,593	Stiff

N	Sandy	16,235	Loose to medium dense soil

Soil Colour Test:

The colour of the soils in Nyandarua (S1, S2, S3 and N are the reading on the soil colour tables) are as Loam soil when dry appeared as dull reddish brown/dull brown and when moist is very dark reddish brown/dark brown, dry clayey soil appeared greyish yellow brown/dull yellow orange/dull brown and brownish black/dark brown/very dark brown when moist. Sandy soil when dry appeared as dark red/dusky red/dark reddish brown and when moist is dark red/very dark reddish brown and Clayey soil appeared to be greyish yellow brown/dull reddish brown/dark reddish brown while when moist appeared to be dark brown/very dark reddish brown

Table 3: Sample Soil Colour Results (source: Revised Standard Soil Colour Charts (Eijkelkamp Agri search Equipment, The Netherlands)

S.No.	Soil texture	Dry	Wet
S1	Loamy	7.5YR/5/3(Dull Brown)	7.5YR/2/3 (Very Dark Brown)
S2	Loam Clayey	7.5YR/5/3(Dull ye Brown)	7.5YR/5/3 (Dark Brown)
S3	Clayey	7.5YR/5/3(Grey Brown)	7.5YR/5/3 (Dull Grey Brown)
N	Sandy	7.5YR/5/3(White Grey)	7.5YR/5/3 (Grey)

Shear Properties (Shear Strength and Angle of Internal Friction):

Shear properties, such as shear strength and angle of internal friction, significantly impact the mechanization and suitability of a potato harvester. Shear strength is crucial for effective soil penetration and extraction, while angle of internal friction affects the soil's flow and discharge. An optimal shear strength is desirable for efficient harvesting, while an angle of internal friction is crucial for smooth soil flow. The shear strength of the soils ranged from 12.3KPa. to 34.5kPa and the angle of internal friction of the soil ranged 15^0 to 35^0. Therefore, the potato harvester can safely operate on the soils, since the soils have a great capacity to resist shear stress. According to (Chaulya and Prasads, 2016) the soil is suitable for machine operation.

Table 4: Shear Properties (Shear Strength and Angle of Internal Friction) Ranges of the Soil Samples

S.No.	Soil texture	Shear strength(kPa)	Angle of internal friction (Degrees)
S1	Loamy	20.5	26
S2	Loam Clayey	14.5	17
S3	Clayey	12.3	13
N	Sandy	34.5	35

Sieve Analysis:

The greater the sieve size, the higher the percent flowing/passing through. More residue was collected in sieves with wider sizes(4mm) than the small sized sieves(0.045mm).

Table 5: Sieve size Analysis Ranges of the Soil Samples

S.No.	Soil texture	Distribution of particle sizes	Clay or sand percentages
S1	Loamy	0.0655	Clay typically below 0.002

S2	Loam Clayey	0.00355	Clay typically about 60%
S3	Clayey	0.00234	Sand typically below 40%
N	Sandy	0.9554	Sand typically above 70%

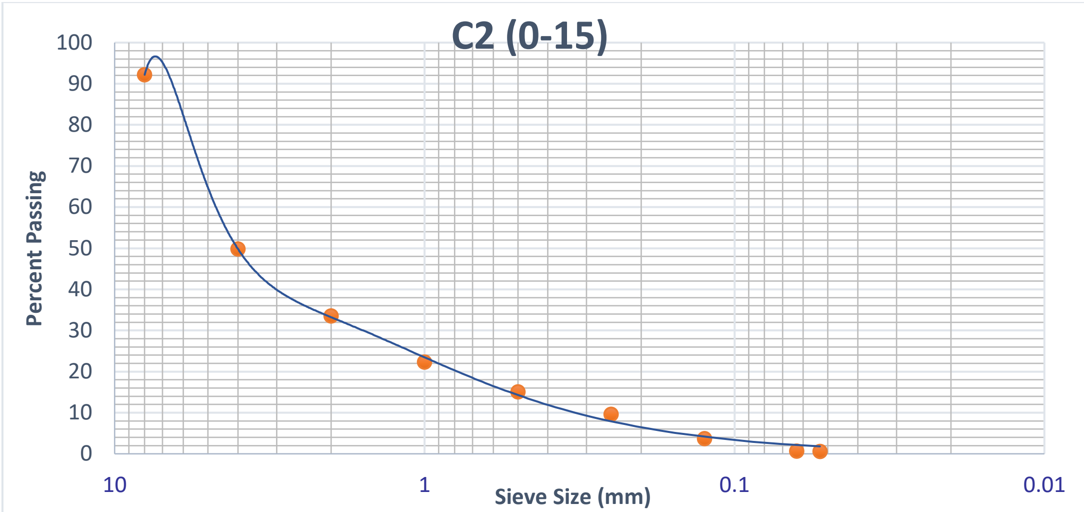

Figure 3.1: A PSD Curve for Sample C2 (0-15) drawn from soil data analysis

Based on Figure 3.1, the Coefficient of curvature (C_c) and Coefficient of Uniformity (C_u), the soils in Nyandarua were classified as Loam (L), Clay Loam (CL)and Clay(C) and sand (S) as per the samples respectively which were proved that they are good for potato mechanisation according to the tests carried out in American Society for Testing and Materials. (ASTM D422): Standard Test Method for Particle-Size Analysis of Soils E-book data.

Bulk Density:
The ratio of pore volume to the volume of solid particles of soil ranged from 51% Clayey) to 75% (Loam-Clayey soil). It was observed that Porosity decreases with an increase in depth, this being contributed by the deposition of smaller soil particles in the lower soil layers. The bulk density of the soils in Nyandarua was from 1.67g/cm^3 (Loam-Clayey) to 1.29g/cm^3 (Clayey). This indicated that the traction of the soil was good hence suitable for the mechanisation according to the tests carried out in American Society for Testing and Materials. ASTM D422: Standard Test Method for Particle-Size Analysis of Soils'-book data.

Table 6: The Bulk Density and the ratio of pore volume of the soil samples

S.No.	Soil texture	Bulk Density Range(g/cm^3)	Ratio of Pore Volume (%)
S1	Loamy	1.1.-1.3	35-50
S2	Loam Clayey	1.3.-1.5	30-40
S3	Clayey	1.3-1.5	25-30
N	Sandy	1.5-1.7	40-60

Triaxial Test:
Mohr stress circles, which define the consolidation stress σ and unconfined yield strength σ in a normal stress σ, shear stress σ diagram this helps in the determination of the traction force of

the soils. Figure 3.2 indicated that the Nyandarua county soils has yielding strength and can withstand the maximum force applied by potato mechanisation.

Table 6: The Angle of internal friction (φ) Cohesion (C) of the soil samples

S.No.	Soil texture	Angle of internal friction (φ)	Cohesion (C)
S1	Loamy	25-35	Low to moderate
S2	Loam Clayey	15-30	Moderate to high
S3	Clayey	10-25	Low
N	Sandy	30-40	Low

Field Ref.: C1 (Sample No.1)

The tested soil was identified as Unconsolidated Undrained, with no pore pressure measurement. The ring calibration was set at 4500 N/mm, and the axial strain rate was maintained at 0.5 mm/min. The minor principal stress, also known as chamber pressure (σ3), was recorded at 0.0500 N/mm^2. During testing, the unit axial load at failure (ΔP) was measured at 1.2667 N/mm^2, resulting in a major principal stress at failure of (σ3+ΔP) 1.3167 N/mm^2. The radius of the Mohr's circle was calculated to be 0.633 N/mm^2, with the center of the Mohr's circle positioned at 0.683 N/mm^2, as shown in Mohr's circle Figure 3.2. These findings suggest that the soils in Nyandarua County are well-suited for potato mechanization, as supported by research conducted by Hossain and his team in 2021**.**

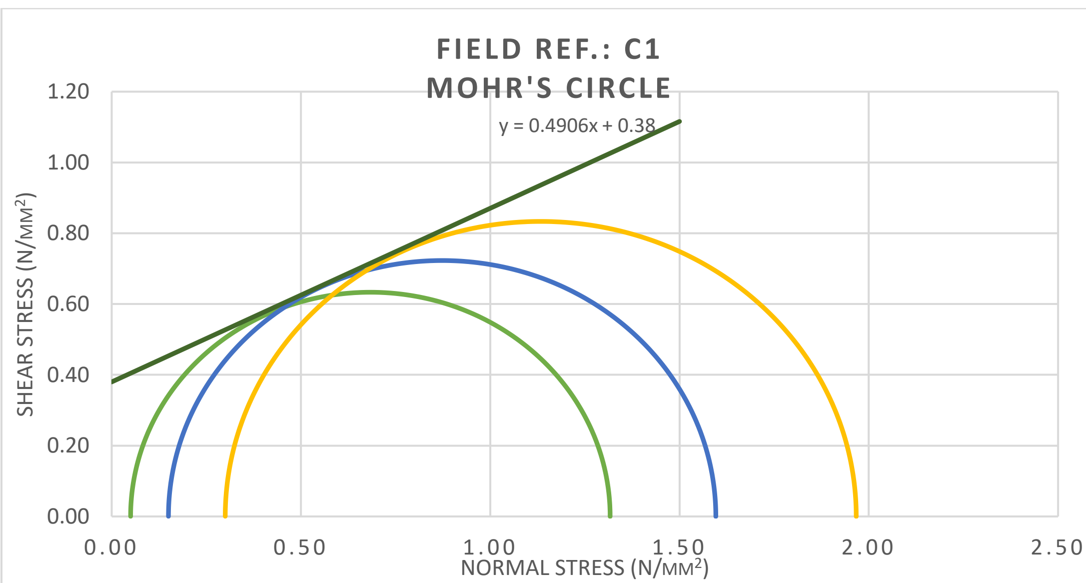

Figure 3.2: C1 Mohr's Circle drawn from soil data collected analysis

Atterberg Limits:

Atterberg Limits serve as vital tests for evaluating the characteristics of fine-grained soils, playing a significant role in determining the feasibility of mechanized potato harvesting. These limits encompass the liquid limit, which signifies the moisture content at which soil transitions from a plastic to a liquid state, influencing soil maneuverability during harvesting. Additionally, the plastic limit represents the lower threshold of soil plasticity, impacting the soil's ability to maintain its shape following mechanical disturbance. Lastly, the shrinkage limit marks the moisture content at which soil shifts from a semi-solid to a solid state, influencing the overall suitability of the field for harvesting operations.

Our experiments on Atterberg Limits in Nyandarua County unveiled intriguing findings. Particularly, the Plasticity Index (PI) of Loamy Soils ranged from 16.5% to 20.9%, while Sandy Soils exhibited the highest PI, averaging at approximately 26% (Figure 3.3). A notable observation was that the Plasticity Index decreased with depth for Sandy and Clayey Soils, but conversely increased with depth for Loamy Soils. These findings underscore the significance of the Atterberg Limits as fundamental indicators of fine-grained soil's critical water content.

The ability of soil to exist in solid, semi-solid, plastic, or liquid states hinges on its moisture content. The compelling data from our study provides compelling evidence that Nyandarua County's soils are well-suited for potato mechanization, even when subjected to high moisture levels. This study's primary focus was to gain a comprehensive understanding of the Atterberg Limits of soils in Nyandarua County, recognizing their pivotal role in assessing suitability for potato harvester mechanization. The liquid limit, with its range of values (e.g., 30% to 54%), delineates varying moisture sensitivities across soil types. Sandy soils, demanding less moisture for optimal movement during harvesting, contrast with clayey soils characterized by higher liquid limits that might pose unique challenges.

Moving forward, the plastic limit emerges as a key parameter, delineating the lower threshold of soil plasticity, signifying the moisture content at which soil retains its shape and moldability. Higher plastic limits indicate superior soil shape retention, offering potential advantages during mechanized harvesting. Calculated as the difference between the liquid limit and plastic limit, the Plasticity Index (PI) affords insights into soil behavior under varying moisture conditions. Soils with elevated PIs display greater plasticity and deformability under the influence of moisture.

In Nyandarua County, our data unveils varying Atterberg Limits contingent on soil texture. Sandy soils exhibit a lower Plasticity Index, implying a lesser degree of plasticity and a more solid nature, even when subjected to higher moisture levels. Conversely, Loamy and Clayey soils, boasting higher Plasticity Index values, display increased plasticity, necessitating meticulous management during mechanization. In conclusion, a profound comprehension of the Atterberg Limits of Nyandarua County's soils is pivotal in the evaluation of their suitability for mechanized potato harvesting. Our study offers invaluable insights into how diverse soil textures respond under varying moisture conditions, providing essential guidance for optimizing mechanized harvesting operations in this region. (See Figure 3.3 for the Plasticity Index data.)

Table 6: The Angle of internal friction (φ) Cohesion (C) of the soil samples

S.No.	Soil texture	Atterberg Limits)		
		Liquid limit (%)	Plastic limit (%)	Plasticity index (%)
S1	Loamy	33	20.1	12.9
S2	Loam Clayey	54	33.1	20.9
S3	Clayey	40	25	15

N	Sandy	30	15	10

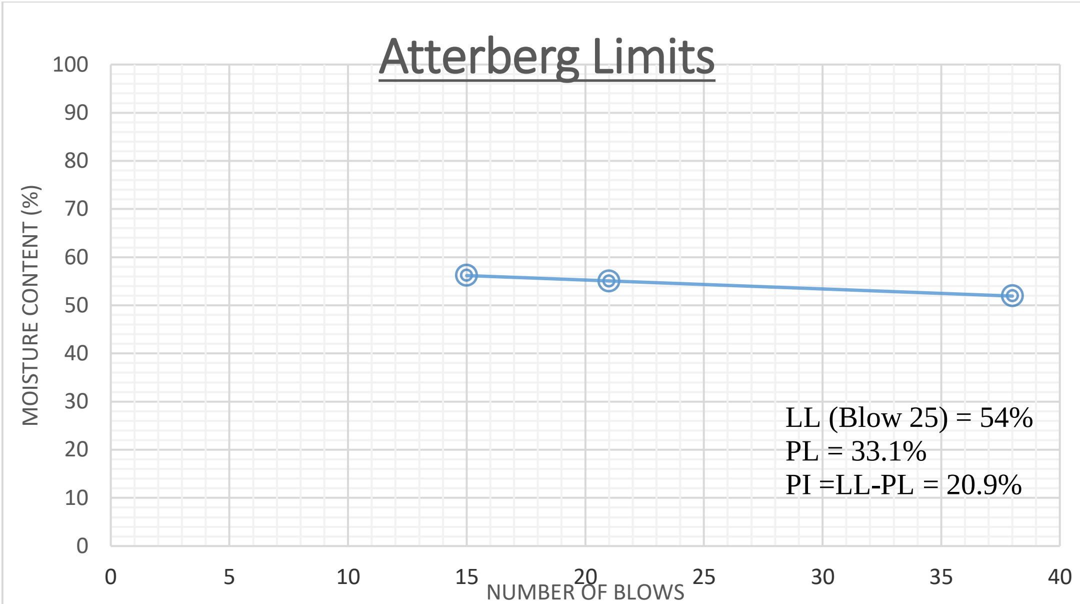

Figure 3.3: Atterberg Limits Graph for Sample L2 (0-15) (drawn from soil data analysis)

Soil Texture Test (Hydrometer Method):
The soils in Nyandarua County generally fell into three classes, namely: Loam, Clay Loam and Sandy Clay Loam.

Spatial Variation of Soil Texture
The reclassified texture table shows that on the basis of texture (Table 2), the highest percentage (58%) is moderately suitable for potato mechanization with high and marginal suitability taking 14% and 23%, respectively and not suitable taking 5%.

Table 2: Spatial Variation of Reclassified Soil Texture (Collected data analysis)

Suitability class	Soil texture	Area (ha)	Area (%)
S1	Loamy	45,965	14
S2	Loam Clayey	189,882	58
S3	Clayey	74,593	23
N	Sandy	16,235	5

Spatial Variation of Landform
The reclassified landform (Table 3) shows that the highest percentage (41%) is least suitable for potato mechanization with high, moderately, and marginally suitable for mechanization taking 21%, 12% and 26%, respectively.

Table 3: Spatial Variation of Reclassified Landform (collected data analysis)

Suitability Class	Landform	Area (ha)	Area (%)
S1	Plain	68,233	21
S2	Low Gradient Foot Slope	39,849	12

S3	High Gradient Hill	84,393	26
N	Ridges	134,204	41

Spatial Variation of Soil Drainage

The reclassified soil drainage (Table 4) shows that the highest percentage (49%) is not suitable for potato mechanization with highly suitable taking 37%, and marginally suitable and moderately suitable taking 14% and 0.2% respectively.

Table 4: Spatial Variation of Reclassified Soil Drainage (collected data Analysis)

Suitability Class	Soil drainage	Area (ha)	Area (%)
S1	**Well-drained**	120,552	36.9%
S2	**Moderately well-drained**	663	0.2%
S3	**Imperfectly drained**	44,714	13.7%
N	**Poorly drained**	160,750	49.2%

Spatial Variation of Surface Drainage

The reclassified surface drainage (Table 5) shows that on the basis of surface drainage, the highest percentage (65%) is highly suitable with moderately, marginally and not suitable taking 2% and 19% and 15% respectively.

Table 5: Spatial Variation of Reclassified Surface Drainage (from collected Data analysis)

Suitability class	Surface Drainage	Area (ha)	Area (%)
S1	Well	210768	65%
S2	Slow	7036	2%
S3	Extremely slow	61323	19%
N	Rapid	47552	15%

Spatial Variation of Soil Depth

Assessing soil depth is essential when considering the suitability of an area for potato harvester mechanization, as it directly impacts crop growth and the choice of machinery. Typically, highly suitable soil depths for mechanization range from 30-60 cm or more, contingent on the harvester's design and planting depth. Moderately suitable soil depths encompass the range of 20-30 cm to approximately 60 cm, subject to local conditions and harvester requirements. Soil depths that fall under the category of unsuitable are characterized by severe hindrances to root growth or potential obstructions to harvester machinery. Soil depths less than 20 cm are generally deemed unsuitable for mechanization. To facilitate the assessment, we classify soil depths based on their suitability for potato harvester mechanization. Very Deep Soil (S1) denotes soil depths of 144,261 hectares, making them highly suitable and classified as "Highly Acceptable" for mechanization. Deep Soil (S2), encompassing 64,517 hectares, also qualifies as suitable for mechanization, although it is slightly shallower than "Very Deep" soils, earning a classification of "Moderately Suitable." On the other hand, Shallow Soil (S3), covering 117,900 hectares, is considered unsuitable for mechanization due to its shallow nature, potential obstructions, or other limitations, marked as "Not Suitable.

It's crucial to note that specific soil depth classifications and their suitability for mechanization may vary from one region to another, contingent on the unique requirements of potato cultivation and the design of the harvester in use, (Nyandarua County Agricultural Development Authority 2021)

Table 6: Spatial Variation of Reclassified Soil Depth from Collected Data Analysis)

Suitability class	Soil depth	Area (ha)	Area (%)
S1	Very Deep	144261	44%
S2	Deep	64517	20%
S3	Shallow	117900	36%

Potato Mechanization Soil Suitability Map

The soil texture, surface drainage, depth, landform, and drainage were graded using the AHP technique, which produced weights ranging from 0 to 100. The findings (Table 7) demonstrate that experts place the greatest emphasis on soil drainage and soil texture, with a combined influence of 29.80%.

Table 7: Pairwise Comparison Results for Soil Sub Criteria (from collected Data Analysis)

	Texture	Drainage	Surface Drainage	Depth	Landform	Weight	Rank
Texture	1	1	2	2	3	29.80	1
Drainage	1	1	2	2	3	29.80	1
Surface Drainage	0.5	0.5	1	1	2	15.80	3
Depth	0.5	0.5	1	1	2	15.80	3
Landform	0.33	0.33	0.5	0.5	1	8.90	5

When all the various qualities of the soil are considered, it is clear that the majority of the land in Nyandarua is suited for potato mechanization. The weights in (Table 7) were applied to the weighted overlay based on the CR<10%. Table 8 findings reveal that only 35% of the available land is very suited for potato mechanization, 31% is somewhat acceptable, and 34% is just slightly suitable.

Table 8: Soil Potential Map for Potato Mechanization (from collected data analysis)

Suitability Class	Area (ha)	Area (%)
S1	114,829	35%
S2	99,706	31%
S3	112,096	34%

Soil Mechanization Suitability Map

Soils have different physical properties (Figure 4) that affect potato mechanization. All the land was found suitable for potato mechanization to the texture criteria, with 14% highly suitable (Loamy), 58% moderately suitable (Loam Clayey), 23% marginally suitable (Clayey) and (5%)

not suitable (Sandy). The suitability of land for potato mechanization is classified based on its texture. Highly suitable soils have a balanced sand, silt, and clay composition, providing good drainage, moisture retention, and workability. Moderately suitable soils have a clayey loam texture, with 58% of land classified as moderately suitable. Marginally suitable soils have a higher clay content but can lead to challenges like compaction, poor drainage, and reduced workability. Not suitable soils have large particle sizes and low water and nutrient-holding capacities, making them less favourable for cultivation and mechanized harvesting.

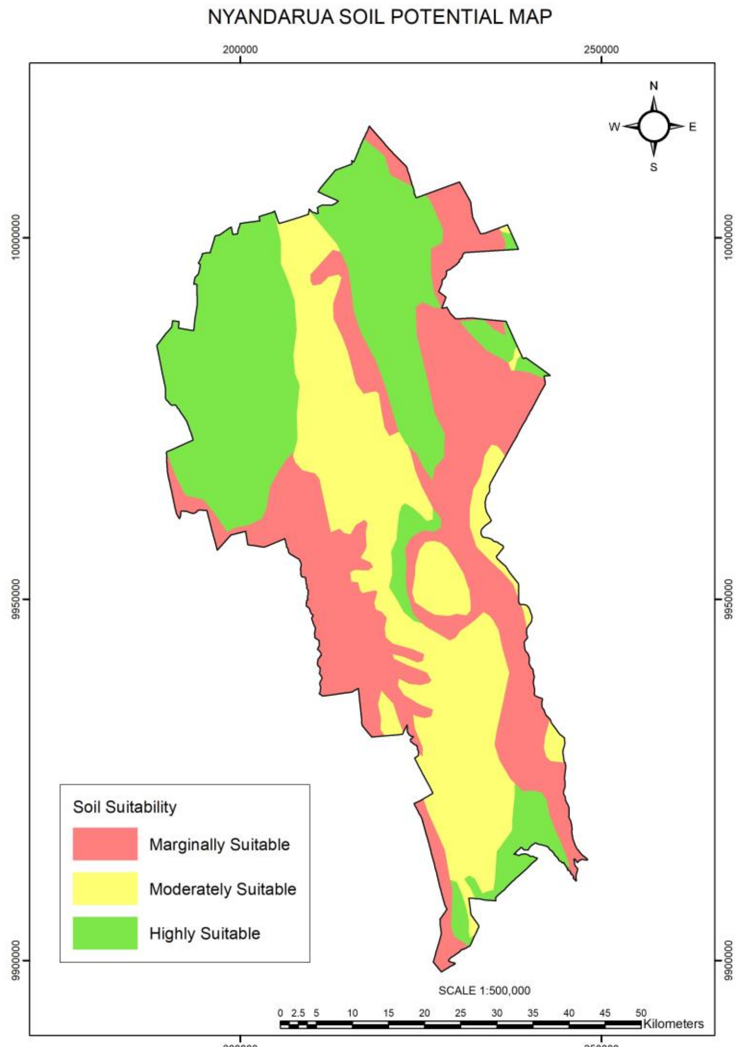

Figure 3.4: Soil Potential Map for Potato Mechanization (Nyandarua County Strategic Plan 2018-2022)

The majority of the soil's physical qualities are influenced by texture, a crucial (Makhmudov, 2020). The textural class of the soil is determined by the relative amounts of clay, silt, and sand (Zulhilmi et al., 2022). Texture determines the suitability of a site for potato mechanization in that when it rains on well-drained loamy soils, and the tractor-mounted potato harvester is prone to avoid getting stuck in this region. For the Loam clayey and clayey parts of Nyandarua, the potato harvester is of good use in areas with good surface drainage, whose area is 65%.

RECOMMENDATIONS

The researcher recommends several recommendations for the implementation and future research of motorcycle potato harvesters. They suggest encouraging farmers to adopt these machines by providing information on their benefits, operation, and maintenance. Extension services and training programs can help educate farmers about mechanization and facilitate adoption. Agricultural organizations and policy makers should promote awareness campaigns targeting regions where manual harvesting is prevalent. Technological advancements should focus on improving the design and functionality of motorcycle potato harvesters, exploring alternative power sources, and integrating precision agriculture techniques.

Future research should explore algorithms and decision support systems to optimize harvesting operations, improve crop quality, and minimize losses. Sustainability and environmental considerations should be assessed, and sustainable practices, such as residue management, cover cropping, and integrated pest management, should be investigated alongside motorcycle potato harvesting. Economic analysis and policy support should evaluate the financial feasibility and profitability of adopting motorcycle potato harvesters, considering factors like investment costs, operational expenses, labor savings, and potential yield gains. Implementing support mechanisms, such as subsidies, grants, or favorable loan schemes, can facilitate the wider adoption of the technology and contribute to agricultural modernization.

CONCLUSION

All soils investigated in Nyandarua had a very rapid hydraulic conductivity class. Fallow land in the county had the greatest cone penetration resistance due to presence of stones at a shallow depth.

The potato harvester can safely operate on the soils, since the soils have a great capacity to resist shear stress. Nyandarua soils exist in large particles rather than small as shown by the sieve analysis. Therefore, the higher the porosity, the smaller the bulk density.

For potato mechanization, 44% of the County is highly suitable, 20% is somewhat acceptable, and 36% is only slightly suitable. The high gradient hill and the low gradient foot slope correspond to shallow soils. High mountain and valley soils are frequently quite shallow and have little to no topsoil. In comparison to shallow soils with comparable textures, deep soils hold more water.

The efficiency of soil drainage can be seen in how quickly free moisture drains from the soil. Poorly drained soils are more likely to produce water. In the study area the highest percentage (37%) is highly suitable for potato mechanization with moderately suitable, marginally suitable and not suitable taking 0%, 14% and 49% respectively. Surface drainage helps in the poorly drained areas (49%) by having excess water diverted from the soil surface directly into streams. A potato harvester thus can suitably be used in such areas where there are less high gradient hills for harvesting potatoes.

The soil in the highly suitable range had a highly suitable depth (very deep soil), moderately suitable surface drainage (slow), highly suitable drainage (well drained), moderately suitable landform (low gradient foot-slope) and moderately suitable texture (clayey). The moderately suitable range soils had a moderately suitable depth (deep), highly suitable surface drainage (well), marginally suitable drainage (imperfectly drained), highly suitable landform (plain) and moderately suitable texture (clayey). The marginally suitable range had a marginally suitable depth (shallow), highly suitable surface drainage (well), not suitable drainage (poorly drained), marginally suitable landform (high gradient hill) and marginally suitable texture (Clayey).

Declaration of Competing Interests:

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Data Availability Statement:

The data generated within this manuscript, including soil analysis results, figures, and tables can be accessed and that any data will be made available upon request.

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