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Influence of intensive potato cultivation on the properties of red ferralitic soils in the "Amistad Cubano-Búlgara" CPA

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Abstract. The agricultural sector in Cuba plays an important role for the economy, with a contribution to GDP of around 20%. However, approximately 67% of agricultural land has some agroproductive limiting factors. This situation is aggravated by the implementation of inadequate farming systems and by the lack of knowledge of the measures to be adopted based on the limiting agro-productive factors of the agroecosystems. In the research, the study of the properties of Red Ferralitic soils (Order Oxisol) is carried out in the agroecosystems intensively dedicated to the cultivation of potatoes (Solanum tuberosum L.), in the CPA "Amistad Cubano-Búlgara", one of the most important production entity in the Mayabeque province. As a result of the research, evident negative impacts are observed on the quality of the soil due to its intensive use and monoculture. This has caused soil degradation, highlighting the low content of organic matter, potassium and phosphorus, along with the reduced cation exchange capacity. Likewise, compaction and poor drainage problems were identified, which negatively affects the development of the crop. Sustainable management measures and the implementation of agroecological practices are proposed to improve the sustainability of food production in the region and counteract the negative effects of intensive agriculture.

1 Introduction

Soil is one of the most valuable resources to ensure food security. The agricultural yields to be achieved depend on its quality and management, as well as its conservation for future generations.

Currently, soil degrading factors are increasing at dizzying speeds, given, among other reasons, to the implementation of conservation practices not adapted to the environment of a specific region [1].

On the other hand, the implementation of intensive farming systems and monoculture, as well as the lack of knowledge of the measures to be adopted based on the limiting agro-productive factors present in a given agroecosystem, leads to marked soil degradation.

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Such is the case of the potato crop, which constitutes the fourth food crop in order of importance on a global scale [1] and the first among the roots and tubers consumed in Cuba, with an average annual production of 300,000 t. This crop is considered one of those prioritized in Cuba, which is why they receive the traditional technological package. This involves the application of high doses of chemical fertilizers and high mechanization. All of which has caused serious problems of soil degradation and contamination, due, among other reasons, to technological indiscipline.

The CPA "Amistad Cubano-Búlgara", whose corporate purpose is the production of agricultural food in order to supply the municipality of Güines, the Mayabeque province and especially the capital of the country, is not exempt from these problems of soil degradation.

In this sense, the study of its soils is required to allow the use of agroecological measures aimed at sustainable food production.

The present work is oriented to the study of the main properties and main agro-productive limiting factors of the soils subjected to intensive exploitation with the cultivation of potatoes (Solanum tuberosum L.) in the Agricultural production cooperative "Amistad Cubano-Búlgara".

2 Materials and methods

The research was carried out in the Central Pivot Machine "Nombre Dios 3", with an area of 13.8 ha belonging to the Cooperative of Agricultural Production "Amistad Cubano-Búlgara" in the municipality of Güines, Mayabeque province. It is located between the geographical coordinates: 22°50`47.04" N, 82°03`45.03`` W and 82°48`1.53" N, 82°02`15.87" W according to the Cuba North coordinate system and Lambert Conformal Conic projection.

For the study of the soil, a test pit was made from which samples of the identified horizons were taken. Agrochemical sampling was also carried out. For this purpose, a composite sample was taken, composed of 5 or 6 simple soil samples per hectare in a zigzag pattern according to the Cuban Standard [2].

The samples were taken at three depths, 0-20 cm, 21-40 cm and 41-60 cm, respectively. These were taken to the laboratory to be dried to constant weight and then sieved at 0.5, 1.0 and 2.0 mm.

For the analyses, the methods described by [3] were used, coinciding with the Cuban Standards.

Organic matter (%): By the Walkley Black method.

pH H_2O: By potentiometry, soil: water ratio 1:2.5.

Ca^{2+} and Mg^{2+} ($cmolc.kg^{-1}$): By extraction with ammonium acetate 1 $Mol.L^{-1}$ at pH 7 and determination by complexometry.

The physical properties were carried out in the Soil Physics Laboratory of the Department of Biofertilizers and Plant Nutrition of INCA following the methodology described by [4], to which the following determinations were made:

Natural or field soil moisture by gravimetric method.

Bulk density ($g.cm^{-3}$): Using cutting cylinders of 100 cm^3 capacity.

Coefficients and stability index of the aggregates: By dry and wet sieving of the aggregates, according to the method of N. I. Savvinov.

Mechanical composition (%) and texture: By the modified Bouyoucos method, using sodium pyrophosphate for the removal of organic matter from NaOH as a dispersant and determination of soil texture by means of the textural triangle.

Lower and upper limit of plasticity, as well as the plasticity index by the Atterberg method.

Other soil quality indicators were also calculated and are presented below.

Calcium-Magnesium ratio:

$$Ca/Mg = \frac{Ca^{2+}}{Mg^{2+}} \quad (1)$$

Base Exchange Capacity:

$$BEC = Ca^{2+} + Mg^{2+} + Na^{+} + K^{+} \quad (2)$$

Saturation by Bases (V-value, %):

$$V = \frac{CCB}{CIC} * 100 \quad (3)$$

Total organic carbon (%):

$$TCO = \%\, MO * 0.58 \quad (4)$$

Total Nitrogen (%):

$$TN = \%\, MO * 0.05 \quad (5)$$

Carbon Nitrogen Ratio (C/N):

$$\frac{C}{N} = \frac{\%\, Corg}{\%\, Nt} \quad (6)$$

Organic Matter Stock (kg. ha $^{-1}$):

$$OMS = Pr\, o\, f * da * \%\, M.O * 1000 \quad (7)$$

where:
da: Bulk density or soil density.

Silt Clay Ratio (S/C):

$$S/C = \frac{\%\, de\ Arena}{\%\, de\ Arcilla} \quad (8)$$

Lithological Index (LI):

$$LI = \frac{\%\, Arena}{100 - \%\, de\ Arcilla} \quad (9)$$

Plasticity Index:

$$PI = LSP - LIP \quad (10)$$

where:
LSP: Upper plasticity limit.
LIP: Lower plasticity limit.

3 Results and discussion

3.1 Analysis of chemical and physico-chemical properties

The organic matter content (Table 1) shows an isohumic distribution. In addition, the low concentration of these elements may be due to the intensive tillage of the soil for more than 30 years for potato cultivation. In addition, these have a natural aggregation, which causes rapid mineralization of organic matter and thus its accelerated loss in the upper layers of the soil.

Table 1. Representation of soil chemical properties

Depth (cm)	OM (%)	pH		K_2O (mg.kg^{-1})	P_2O_5 (mg.kg^{-1})	Relation C/N
		H2O	KCl			
0-20	2.04	6.64	5.63	3.54	53.45	11.3
21-40	1,93	6.03	5.76	2.32	36.89	11.13

In this same table it is observed that potassium at all depths is low, therefore it does not satisfy the needs of the potato crop. This may be due to the washing to which these soils have been subjected. In this regard [5] states that the losses of this element due to washing are higher than those of phosphorus and lower than those of nitrogen, this is retained directly by the humic complex of the soil, with the losses that occur in soils due to coarse texture being important. and low Base Exchange Capacity (BEC), although according to some authors they affirm that losses due to washing do not constitute a problem for most soils, these can be between 5–250 kg.ha-1 per year, which is related with the intensity of precipitation and vegetation cover [6].

With respect to phosphorus, it is evident that its contents are classified as medium in the first 20 cm of depth and low in the depth of 20 to 40 cm. This is because phosphorus tends to be strongly retained in the clay complex as an insoluble element for plants, often appearing as a limiting element [7]. This element is absorbed in a soluble state, but when introduced into the soil it quickly passes into soluble forms, not available for cultivation [8, 9].

In the soils of the Ferralitic (Oxisol), where kaolinite clay type (1x1) predominates, the pH tends to decrease as shown in Table 2. However, it still has a value close to neutrality. If it is considered that the optimal pH for potato cultivation ranges between values of 4.5 and 7.5 in KCl [10], it can be concluded that this indicator does not affect the development of the crop.

Likewise, when evaluating the carbon-nitrogen relationship, it is evident that it is classified as mediated, which implies that the speed of transformation of organic matter in the soil, and with it, the time of incorporation of nutrients into the soil occurs in a period of between two to three weeks.

Table 2. Representation of the cation exchange capacity of the soil studied

Depth (cm)	**Exchange Complex cmol $^{(+)}$.kg^{-1}**					**Ca/Mg**	**V %**
	Ca^{2+}	**Mg^{2+}**	**K^{+}**	**Na^{+}**	**BEC**		
0-20	9,82	5,25	0,53	0,09	15,69	1,87	95,61
21-40	9.17	3.88	0.32	0.03	13.40	2.36	96.78

The previous table shows the base exchange capacity, which appears low at the depth from 0 to 20 cm, as well as at the second depth evaluated. This is characteristic of this type of soil, where a high % of clay (1x1) kaolinite and iron and aluminum oxides and hydroxides predominate. This coincides with the results reported by some authors when studying the physical properties of soils in relation to their degradation and evolution [11, 12].

Likewise, the calcium magnesium ratio is below the permissible range, which may be due to the contribution of carbonates from the water. All of which prevents the adsorption of calcium by the potato crop, which affects its normal development.

3.2 Analysis of physical properties

When we analyze the texture, it is possible to see that the first depths make up the A horizon, with a depth of approximately 45 cm. This behavior is due to the fact that in the first two depths the clay difference does not exceed 4%. This is necessary for Horizon change to exist [13]. The opposite occurs at the third depth evacuated, where there is a change in clay content between this horizon and its adjacent ones, with the formation of an argillic horizon, since the differentiation between the two horizons exceeds the required 8 %. It also shows a low silt-clay ratio, which indicates the high degree of evolution [14, 15].

On the other hand, the existence of anthropic compaction has been observed in these soils due to the presence of hardened layers on the soil surface (Figure 1). This is confirmed by analyzing the behavior of soil density in Table 3, where its values are above 1.20 Mg.m^{-3}, which implies soil compaction. This type of compaction is caused by the excessive use of agricultural machinery on cultivated soils, as well as by the non-use of the multi-ploughing and tiller when the soil has required it.

This compaction is typical of soils subjected to intensive cultivation without taking into account soil conservation measures and generates an important conflict of use between the suitability of the land and the requirements of the crop for its adequate development with intensive soil management [16]. On the other hand, the presence of compacted horizons affects the potato crop as it can limit its adequate root development by reducing the effective depth due to compaction. This coincides with what has been suggested by [17], who state that the potato needs an effective depth of 50 cm for the adequate development of its tubers.

In this case, the real density of the soil or density of the solid phase remains high at a depth of 60 cm, which is characteristic of these soils because the organic matter content decreases and the mineralogical content increases.

The analysis of the lithological indices (LI), also reported low, less than one, corroborating the high degree of evolution of these soils. This behavior coincides with the results of [15].

Fig. 1. Representation of the ploughing floor in a Red Ferrallitic Compacted Soil

The quantities of sandy fractions and the ratio (L/A), show that we are in the presence of an evolved soil where the potential fertility is low because the sandy fractions are low and basically constituted by quartz, therefore the future transformation process is limited, so it is necessary to conserve the mechanical particles that make up these soils and the management must be adequate for their preservation.

Table 3. Representación de las propiedades físicas del suelo

Depth (cm)	Texture (%)			S/C (%)	IL (%)	Ds ($Mg.kg^{-1}$)	Dfs ($Mg.kg^{-1}$)
	Sand	Silt	Clay				
0-20	11,7	18,8	69,5	0,23	0,43	1.09	2.78
21-40	12,1	15,8	72,1	0,1	0,5	1,32	2,77
40 -60 +	10,4	8,4	81,2	0,1	0,5	1.19	2.79

The density of the solid phase or specific weight (Dfs) behaves high in these soils, increasing slightly throughout the profile. In these soils the densities are high or very high inside the profiles due to the predominance of iron oxides. and aluminum, as well as a smaller number of interchangeable bases [18].

Similarly, Table 4 shows that the Lower Limit of Plasticity (LIP) or Plastic Limit at all depths studied presents the same trend: they are greater on the surface and decrease with depth. This may be due to the decrease in organic matter. While the Upper Plasticity Limit (LSP) at all depths studied tends to increase. This may be given by the amount of clay present and the decrease in OM in them.

Table 4. Analysis of the plasticity, porosity and humidity of the soil studied.

Depth (cm)	LIP (%)	LSP (%)	PI (%)	Evaluation	Pt (%)	Pcap (%)	Pa (%)	VN (%)
0-20	18,4	42,3	21,15	Slightly plastic	59,395	42,03	14,36	25,45
21-40	18,91	43,4	23,25	Slightly plastic	63,08	39,18	13,89	23,87
41-60+	17.5	44.7	25.4	Slightly plastic	61.98	43.22	15.77	23,02

LIP: Lower Limit of Plasticity, LSP: Upper Limit of Plasticity, IP: Plasticity Index, PT: Total Porosity, P.cap: Capillary Porosity, Pa: Aeration Porosity, VN: Volume Change.

The plasticity index (PI) tends to increase with depth, behaving as plastic to very plastic. This correlates with the results obtained with the volume change (VN), whose values allow the clay present in the studied soil to be assessed with high expandability.

Total Porosity (TP) is high at all depths evaluated. However, the aeration porosity is at the critical limit. Which is related to the presence of the high apparent density that exists at the depths evaluated. In this regard, it is proposed that for Aeration porosity to have optimal values, it must be between one half and one third of the total porosity [19]. This situation can affect the normal development of crops, given that in these conditions the internal drainage of the soil is affected, which can be much more detrimental to the cultivation of raisins, since their tubers can be exposed to disease attacks. fungus attracted by soil moisture. In addition, the breathing capacity of the roots found in the soil is also affected. Similar behavior is reported for the cultivation of cassava in soils subjected to high anthropization conditions [20, 21].

The aggregates of greatest agronomic importance are those of the size of 5-1 mm [22]. When evaluating the results of Table 5, it can be seen that these aggregates represent 47.8% of the total, all of which is an indicator of the adequate structural stability of these soils. This is corroborated when analyzing the sum of the aggregates with the size of 0.25 to 10 mm, which represent 72.85% of the total aggregates. Likewise, the structural stability index is greater than 1, which corroborates the stability of said soils.

Table 5. Analysis of structural stability

Depth (cm)	Sieve							
	>10	**10-7**	**7-5**	**5-3**	**3-2**	**2-1**	**1-0,5**	**0,5-0,25**
0-20	24,27	10,50	10,15	24,92	0,92	21,96	4,40	2.87
21-40	23,00	12,90	12,82	27,44	1,14	18,27	2,18	1,05
41-60+	22.5	11.55	12.93	28.10	1.19	18.30	2.09	1.07

3.3 Proposal of the Action Plan aimed at the sustainable management of lands dedicated to potato cultivation in the CPA “Amistad Cubano Búlgara”

Based on the analysis of the agro-productive limiting factors present in the study area, as well as the criteria of the social actors of the production entity and a group of specialists with a high degree of expertise on the topics addressed in the research, it was possible establish a group of conservation measures aimed at mitigating the main agro-productive limiting factors with an agroecological approach.

3.3.1 Presence of compaction and low effective

Considering the marked anthropogenic compaction found in these soils, it is recommended to establish rigorous measures that lead to the reduction of tillage. In addition, the possibility of using the subsulator, at least once a year, at a depth of between 30 to 40 cm, as well as the application of organic matter and green fertilizers, must be taken into account in compliance with cultural care. Additionally, the following measures must be taken into account:

- Proper tillage system: reduced tillage, minimum tillage and zero tillage.
- Use of organic amendments, biofertilizers and green fertilizers (Canavalia ensiformis, Crotalaria juncea and Mucuna aterrimum).
- Avoid the use of heavy equipment to reduce soil compaction.
- Planting time: Plant crops before the beginning of the rains so that the soil has a vegetative cover that protects it.
- Use appropriate crop rotation systems.
- Use crops with the possibility of being incorporated into the soil as organic matter and thereby contributing to its decompaction, as is the case of white radish.

3.3.2 Low organic matter content, poor internal soil drainage and inadequate internutrient ratio, among others

As part of the soil preparation, it is recommended to replace the conventional system (6 or 7 tillages) with a system that implicitly reduces the tillage of the soil, without affecting its adequate conditioning for the development of the crop. Likewise, excessive mulching of the soil should be avoided and carried out only depending on the type of seed to be established and reduce the time that the soil remains uncovered or bare to no more than 20 days, among other actions.

While in relation to cultivation actions, it is recommended to incorporate crop remains to promote the incorporation of nutrients and water into the soil, as well as promote biological activity. Likewise, it is suggested to alternate animal traction with mechanized soil preparation, in cases where possible, in order to reduce soil compaction; establish intercropping or association crops, practice crop rotation or mix crops with species that provide nitrogen to the soil, among other actions.

4 Conclusions

The continued use of the soil with potato cultivation has caused its degradation with a marked presence of compacted layers due to the intensive tillage to which it is subjected. This affects the air-water balance and the proper development of crops and increases the economic cost of the work to be implemented.

The main chemical properties of the soils that constitute limiting factors for the adequate development of the potato crop were the content of organic matter and the content of assimilable potassium and the calcium-magnesium ratio, which affects the adequate physiological development of the crop.

From the analysis of the lithological index, the degree of evolution of the soils was corroborated, with the evident presence of the formation of an argillic horizon, typical of compacted Red Ferralitic soils.

Given the marked presence of agro-productive limiting factors, among which low chemical fertility, poor drainage and compaction stand out, the management of the studied soils in an efficient manner and contextualized to the requirements of agricultural uses established in the entity.

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