

Soil Organic Matter and Grain Yield of Rainfed Maize in Luvisols of Campeche, México

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Abstract

The organic matter is an important soil component, due its favorable effects on soil physical and chemical properties and, by consequence, on crop yields. So, the objective of this work was quantify the changes through the time of soil organic matter in rainfed maize (*Zea mays* L.) system, in a period of 30 years of continuous crop and in relation to system of natural vegetation system, and also the effects of these changes on the crop yield, in Luvisols soils of State of Campeche, México. In production cycle of 2004, 53 farmer plots in rainfed maize system of different land use time and five sites of forest natural vegetation system were sampled for soil, to quantify physical and chemical properties of soil, and it was taken data about climate, system management and crop yield. The data were analiced by regression analysis, considered the organic matter as function of land use time and factors of soil and management of system, and the crop yield as function of soil organic matter and factors of soil, climate and management of system. The soil organic matter diminished from 5.68% in forest natural vegetation system to 3.59% after 16 - 30 years of cultivation, and the soil annual incorporation of vegetative mulch (weeds and stubble of maize) increased the organic matter from 0.14% after 1 - 5 years to 0.46% after 16 - 30 years of cultivation. Without fertilization, the diminution of soil organic matter caused 907 kg·ha⁻¹ less of maize yield, and the fertilization with 200 kg·ha⁻¹ of diamonic phosphate (36 kg·N·ha⁻¹ and 92 kg P₂O₅ ha⁻¹) increased the maize yield 1224 kg·ha⁻¹ after 1 - 5 years and 1421 kg·ha⁻¹ after 16 - 30 years of cultivation, but not compensated less maize yield of 711 kg·ha⁻¹ due the diminution of soil organic matter.

Keywords

Zea mays L., Annual Crops, Forest Natural Vegetation, Land Use Time, Soil Properties

1. Introduction

Organic matter is an important component of the soil, as it has favorable effects on physical, chemical and biological properties, and consequently, on the productivity of agricultural systems [1] [2]. Among its effects is: its cementing action on the particles, which promotes the formation of aggregates, which increases the flow of water, air and heat, and the capacity of infiltration and retention of water; in the process of decomposition and mineralization of organic waste, it provides macronutrients, especially N, P and S, as well as micronutrients; increases the capacity of exchange of soil cations, thereby reducing nutrient losses from leaching; and, biological activity increases, with its beneficial effects on production systems [3] [4] [5] [6]. The organic matter content of the soil is a function of the relationship established between the addition of organic waste and the rate of mineralization over time, and depends on the temperature and humidity conditions of the medium, pH, nutrient content and type and amount of soil colloids, the composition of organic waste and the conditions of aeration to which the soil is subjected [6] [7] [8]. In the systems of annual crops, especially intensive and mechanized, a decrease in the organic matter of the soil tends to occur, due to the greater removal and aeration of the soil by the tillage, which favors the decomposition and mineralization of the organic matter by the flora soil microbial [9] [10] [11]. Another cause of the decrease in soil organic matter is the burning of crop residues, which decreases the incorporation of organic waste into the soil [4] [12]. The study on the changes of the organic matter of the soil in the systems of annual crops is done observing the evolution of them in the time, from the natural ecosystem, and the effect of these changes on the productivity of the system by, if necessary, the decrease in crop yields [6] [13] [14] [15]. In the state of Campeche, Luvisoles soils occupy about 270,000 ha [16]. These soils were covered by medium forest and high perennial rainforest [17], and as the agricultural frontier expanded since the 1960s, they have been gradually incorporated into agriculture and livestock [18]. In this type of soil, the rainfed corn system is cultivated in approximately 140,000 ha [19], while a large part of the irrigation units (24 thousand hectares) are located in these soils, sowing mostly with vegetable and fruit crops [20]. The favorable physical characteristics of the Luvisols, as well as climatic conditions with annual rainfall of 900 to 1200 mm and, where appropriate, the availability of irrigation, has resulted in them having been subjected to intensive exploitation, both of annual and fruit crops like grasslands, characterized by high mechanization, burning of crop residues and low fertilization for the former, and poor management of the prairies. This has caused the deterioration of the soil, by loss of organic matter and fertility and by compaction, and finally a decrease in productivity [21] [22]. In non-disturbed ecosystems in Luvisoles of the State of Yucatán, Pool y Hernández [23] found soil organic matter contents of 26.2% for a depth of 0 to 3 cm, which decreased to 7.5% after four years of cultivation with a rainfed corn system. In these same ecosystems, Mariaca *et al.* [24] observed decreases in soil

matter at depths of 0 to 3 and 3 to 10 cm, from 26.1% and 24.6%, to 5.6% and 4.9%, respectively, after six years of cultivation with a rainfed corn system. On the other hand, in Luvisoles del Estado de Campeche, Turrent *et al.* [25] and Cuanalo *et al.* [26] found organic matter values of 2.8% to 3.0% in the first 20 cm, after 24 to 28 years with corn monoculture. A common practice in the Luvisols of the state of Campeche is the burning of crop and weed residues, which decreases the incorporation of organic matter into the soil, and may be the cause of its decrease, although Pool y Hernández [23] and Mariaca *et al.* [24] found no significant effect of burning crop residues on the organic matter content of the soil in the first 10 cm in a period of six years under corn cultivation. Regarding the effect of the decrease in soil organic matter on crop yields, Mariaca *et al.* [24] found a sharp decrease in yield of rainfed corn system after six years of continuous use with this crop, which was recovered with the application of fertilizers (values not indicated). On the other hand, Mariaca *et al.* [24] found increases in yields in rainfed corn system after eight continuous cycles in Luvisoles and Litosoles soils, of:

1) Non-burning on the burning of crop residues and weeds, of 75.5%. 2) The incorporation of organic matter (2 t-year⁻¹ of litter) on non-incorporation, of 46.3%; and 3) The application, of fertilizer (40-60-0 in the first six years, 30-80-0 in the last two years) on the non-application of 39.5%.

The objective of the present study was to determine the changes in the organic matter content of the soil in the rainfed maize system, over a period of 30 years and with respect to a natural forest vegetation system, and the effect of these changes on the corn grain production, in Luvisoles soils of the State of Campeche.

2. Materials and Methods

The study was carried out in 2004, in the municipality of Hecelchakán, Campeche (**Figure 1**), in the area located between 19°09'04" and 20°09'04"N and 87°50'50" and 90°04'58"O. The predominant soils are Luvisols, which are characterized by presenting a flat relief and slopes less than 1.5%, reddish black colors (10R 2.5/1) to dark red (10R 3/2), depths greater than 1.0 m, texture clay (usually with more than 60% clay), very efficient internal drainage, pH between 6.8 and 7.2, and organic matter contents of about 2.8% in soils under cultivation and up to 9.0% in soils under forest vegetation [22] [27] [28].

The climate is AW1, which corresponds to a warm sub-humid with summer rains, with annual rainfall of 900 to 1200 mm, of which 85% occur between May and October, and average annual temperature of 25.5°C to 26.4°C [16] [26]. In the rainfed corn system, planting is done when the rains begin, which occurs in the months of June to July, with the harvest falling in the months of November to December; mainly improved varieties (VS-536 and C-343) are used; soil management, sowing and harvesting are done mechanically; weed control is done with herbicides; pest control is only carried out by a few producers;

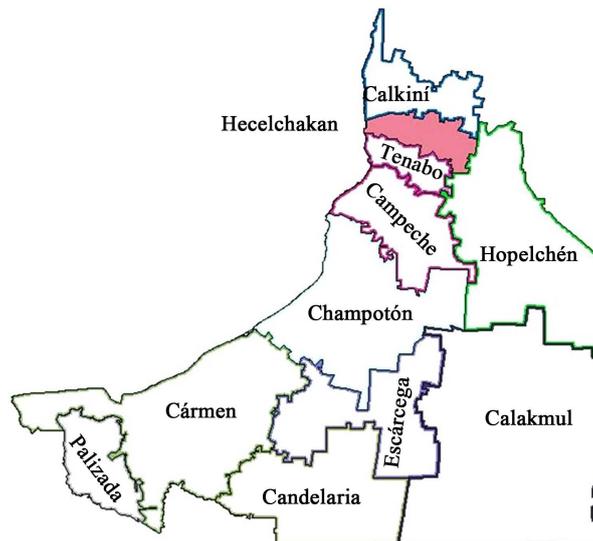


Figure 1. Map of the state of Campeche, México, indicating its municipalities.

fertilization is normally done with diammonium phosphate (N-P₂O₅-K₂: 18-46-0), in quantities of 50 to 150 kg·ha⁻¹; yields vary between 0.8 to 2.9 t·ha⁻¹, which is associated with the low level of some technological components used by producers [16] [22]. In the study area, corn began to be sown after the clearing of the forest, in a variable period per producer, from 1 to 5 years. According to this, the years of land use after clearing were grouped in periods from 1 to 5, 6 to 10, 11 to 15, 16 to 20, 21 to 25 and 26 to 30 years. In each period of time a community was selected that complied with the requirements of having Luvisoles soils and cultivation areas not less than 1.0 ha, and that eight producers agreed to participate in the study, which resulted in eight repetitions per period; This last requirement meant that in two periods of time it was necessary to consider two communities. On the other hand, within the area covered by the cultivation system, five natural forest vegetation sites distributed therein were located as a reference system. Cooperating producers and their plots were collected information on soil, climate, production technology and crop yield. At a general level, soil properties, such as depth, slope, color and texture, were determined in order to corroborate whether the soils of the different locations were similar, and could be analyzed together. Soil sampling was done at a depth of 0 to 20 cm, using a zig-zag procedure, taking 15 to 20 subsamples per plot at the time of harvest, and at the five sites of natural forest vegetation, to obtain a composite sample [29]. In the soil samples physical properties (sand, silt and clay, real and apparent density, field capacity, permanent wilting point) and chemical (pH, electrical conductivity, organic matter, nitrates, interchangeable cations (Ca²⁺, Mg²⁺ were determined. K⁺ and Na⁺), soluble K, P Olsen and micronutriments (Fe, Mn, Cu and Zn), following the methods of the Official Mexican Standard NOM-021-RECNAT-2000 [30]. The climatic information consisted of the daily precipitation of the meteorological stations of the study area, in the towns of Sahcabchén,

Edzná, Kankí, Tinún and Cayal, based on which the rainfall in each plot was estimated by a linear approximation. The technological information was obtained from the producers, and included the management of crop residues, soil preparation, variety, planting date, plant density, planting method, fertilization, weed and pest control, and also yield. The changes in soil organic matter in the maize system over time and in relation to the natural forest vegetation system were analyzed based on the time of land use and soil factors (physical and chemical properties) that could affect organic matter and explain possible differences between localities outside the time of land use, through regression analysis, following the procedure proposed by Volke [31] for non-experimental information. Time periods from 1 to 5, 6 to 10, 11 to 15, 16 to 20, 21 to 25 and 26 to 30 years were coded with values of 2.5, 7.5, 12.5, 17.5, 22.5 and 27.5, respectively, at one the forest natural vegetation system was coded as 0, since it corresponded to the condition without land use when the content of organic matter was at its maximum value, and for him it was considered an auxiliary variable in case its content of Soil organic matter may not follow the model of change in organic matter over time (for the temporary maize system, auxiliary variable = 0; for the natural forest vegetation system, auxiliary variable = 1). To determine the effect of soil organic matter on yield, a model of crop yield was considered based on soil organic matter and soil, climate, and management factors, since they could also be affecting yield, and analyzed using the regression procedure proposed by Volke [31] for non-experimental information. The variety was coded as an auxiliary variable, with a value of 0 for variety V536, mainly used by producers, and 1 for newly introduced hybrids.

3. Results and Discussion

3.1. Physical Properties of Soil

The soils of the different periods of time presented depths greater than 1.5 m and slopes less than 1%, and **Table 1** shows the contents of sand, silt and clay, wet color, humidity at field capacity and permanent wilting point of the soil, as means for periods of time. The values of these physical properties confirm that the soils of the different periods of time were acceptably homogeneous, as to be considered together [22] [32].

3.2. Changes in Organic Matter over Time

Table 2 shows the contents of soil organic matter at a depth of 0 to 20 cm per period of time of land use for the rainfed maize system and the natural forest vegetation system (SVN) considered at the beginning, since it was split from the clearing. A decrease in soil organic matter is observed from the SVN with 5.68% to 4.80% in the period of 1 to 5 years, 4.65% in the period of 6 to 10 years, 4.21% in the period of 11 to 15 years, and 3.59% in the periods of 16 to 30 years, when it apparently reached a balance of it on the ground.

Table 1. Average values of physical properties of the soil by period of time in the rainfed maize system and the natural forest vegetation system (SVN).

Time interval (years)	Sand (%)	Silt (%)	Clay (%)	Field capacity (% weight)	Permanent wilting point (% weight)
SVN*	8.7 ± 4.4	16.8 ± 3.0	74.5 ± 6.0	34.6 ± 1.8	25.5 ± 1.1
1 - 5	6.2 ± 3.4	18.9 ± 4.5	74.9 ± 4.7	32.8 ± 1.0	24.4 ± 1.0
6 - 10	9.0 ± 2.8	23.2 ± 4.3	67.7 ± 6.2	32.8 ± 0.7	24.3 ± 0.4
11 - 15	10.0 ± 6.4	19.8 ± 5.4	70.2 ± 8.9	32.7 ± 11.6	24.8 ± 8.7
16 - 20	6.2 ± 3.0	20.0 ± 4.3	73.9 ± 6.5	32.3 ± 1.1	24.8 ± 0.7
21 - 25	7.4 ± 3.6	17.7 ± 5.0	75.8 ± 7.8	31.6 ± 0.6	25.1 ± 0.7
26 - 30	8.7 ± 2.4	17.9 ± 1.8	74.8 ± 3.8	32.3 ± 1.0	25.0 ± 0.9

*SVN = Forest natural vegetation system.

Table 2. Average content of soil organic matter by period of time, in the rainfed maize system and the natural forest vegetation system (SVN).

Time interval (years)	Soil organic matter (%)	Moisture color
SVN*	5.6 ± 0.3	10 R2.5/2-10 R3/2
1 - 5	4.8 ± 0.4	10 R2.5/1-10 R2.5/2
6 - 10	4.7 ± 0.2	10 R2.5/2-10 R3/2
11 - 15	4.2 ± 0.2	10 R2.5/2
16 - 20	3.4 ± 0.2	10 R2.5/2
21 - 25	3.7 ± 0.3	10 R2.5/1-10 R3/2
26 - 30	3.7 ± 0.2	10 R2.5/2-10 R3/2

*SVN = Forest natural vegetation system.

The values of organic matter in the periods of 21 to 30 years are higher on average than those of the period of 16 to 20 years, in 0.29% and 0.31% respectively, in which other soil or management factors that favored the accumulation of organic matter in the soil, but not determined. Also, these same values are higher than those indicated by Turrent *et al.* [25] and Medina *et al.* [22] for the same soils and a continuous corn cultivation period of 28 years, from 2.8% to 3.0%.

On the other hand, although the color of the soil presented variations between periods of time, these were not related to the content of organic matter, as could be expected, since higher levels of organic matter are expected to have darker colored soils [33] [34] [35] [36].

The decrease in soil organic matter due to the time of cultivation in the SMT and in relation to the SVN was expressed by the following regression model:

$$M = 5.701 - 0.555 E^{0.5} + 0.0267 E$$

$$(CME = 0.119, Pr.F = 0.0001, R^2 = 0.791)$$

where: M = soil organic matter (%); E = coded variable for time periods of land use: 0 = natural forest vegetation system, 2.5 = 1 to 5 years, 7.5 = 6 to 10 years,

12.5 = 11 to 15 years, 17.5 = 16 to 20 years, 22.5 = 21 to 25 years and 27.5 = 26 to 30 years.

The regression model did not include the auxiliary variable for the SVN, which means that it explains the decrease in organic matter as a function of the time of land use and in relation to the SVN; On the other hand, it also did not include soil factors, such as the physical and chemical properties considered, that could have affected the behavior of the organic matter, from which it is deduced that its change in time was due to a greater extent to the time of use of the ground. The decrease in organic matter over time in soils under annual crops, and from the previous natural vegetation system, by the action of microorganisms, is widely documented in the literature [9] [10] [11]. For given soil and climate conditions, the decomposition and mineralization of organic matter will be greater the greater the removal of the soil by tillage and the non-incorporation or burning of crop residues. In the present case, although producers who have their own machinery follow a system of soil management determined over time, for producers who do not have machinery the situation tends to be different, since they do not always have the necessary machinery and on time. This makes its soil preparation system differ over time and, consequently, it is difficult to determine the effect of soil removal and waste management on soil organic matter.

The soil preparation work carried out by the producers are: a plow pass, by a few; from none to two steps of semi-heavy dredge; and, from none to three steps of light dredge. On the other hand, producers may or may not perform a mechanical cut of weeds that develop after harvesting or burning of them and crop residues, before the start of soil preparation for the next crop cycle. From all these works, it was found that the mechanical cutting of weeds and their incorporation into the soil, together with the crop residues, with the soil preparation work, increased the organic matter, according to the following regression model:

$$M = 5.800 - 0.767 E^{0.5} + 0.0592 E + 0.0978 E^{0.5}R$$

$$(CME = 0.084; Pr.F = 0.0001, R^2 = 0.762)$$

where: M = soil organic matter (%); E = coded variable for periods of land use time: 2.5 = 1 to 5 years, 7.5 = 6 to 10 years, 12.5 = 11 to 15 years, 17.5 = 16 to 20 years, 22.5 = 21 to 25 years and 27.5 = 26 to 30 years; R = incorporation of organic waste into the soil (without incorporation, R = 0; with incorporation, R = 1).

Table 3 shows the estimated average contents of soil organic matter over time in the SMT, without and with the incorporation of organic waste. In the period of 1 to 5 years, the highest organic matter content due to the incorporation of waste was 0.14%, a value that increased to 0.46% in the periods of 16 to 30 years. Although the incorporation of waste increased the organic matter content of the soil, which indicates the importance of this practice, this increase did not compensate the losses of organic matter due to the continuous use of the soil, with temporary corn in the present case.

Table 3. Estimated average content of soil organic matter over time in the rainfed maize system, without and incorporating organic waste.

Time interval (years)	Soil organic matter (%)		
	without waste incorporation	with waste incorporation	difference between with and without incorporation of waste
1 - 5	4.74	4.88	0.14
6 - 10	4.14	4.41	0.27
11 - 15	3.83	4.17	0.34
16 - 20	3.63	4.04	0.41
21 - 25	3.49	3.96	0.47
26 - 30	3.41	3.92	0.51

3.3. Effect of Soil Organic Matter on Production

The effect of changes in soil organic matter over time on crop yield, considering soil and climate factors, and system management, was expressed by the following production function:

$$Y = -64933 + 8705.5 O^{0.25} + 478.68 (La-50) - 1.0595 (La-50)^2 + 684.32 (Ld-25) - 2.0912 (Ld-25)^2 - 3.0363 (La-50)(Ld-25) + 565.66 V + 0.75700 (D-20)^2 + 81.216 Hd - 1.9045 Hd^2 + 1.4232 F^{1.5} - 9.4600 O^{0.5}F$$

(CME = 165 430, Pr.F = 0.0001, R² = 0.896)

where: Y = yield of corn (kg·ha⁻¹), M = organic matter of the soil (%), La = rain in the period of 30 days before the male flowering (mm), Ld = rain in the period of 20 days after male flowering (mm), V = variety of corn (0 = VS-536, 1 = C-343, Nutria, Z-30/C-343, H-Pioneer), D = plant density (thousand plants ha⁻¹), Hd = herbicide after planting (days after planting), F = diammonium phosphate fertilizer (N-P₂O₅-K₂: 18-46-0) (kg·ha⁻¹).

The time period factor was not included in the production function obtained, which should be understood in terms of the correlation between the decrease in soil organic matter over time and time periods ($r = -0.874$, $p = 0.01$), and it was the organic matter that was included and affected the corn yield. On the other hand, other factors that affected the performance, in a positive way, were: rain in the period of 30 days before and 20 days after male flowering, improved varieties of corn, C-343, Nutria, Z-30/C-343 and H-Pioneer, above the variety of producers, VS-536, plant density, herbicide application after sowing and fertilization with diammonium phosphate(N-P₂O₅-K₂: 18-46-0).

According to the production function, **Table 4** shows the estimated average yields of corn for the periods of time and their corresponding values of soil organic matter, with and without 200 kg·ha⁻¹ of diammonium phosphate, at average rainfall values in the period of 30 days before (156 mm) and 20 days after (50 mm) of male flowering, and optimal herbicide application opportunity after sowing (20 d); and, of 50,000 ha⁻¹ plants; at the same time as for the improved variety of corn VS-536, which is what the producers use.

Table 4. Estimated average yield of seasonal maize by time period and its respective soil organic matter content, with and without fertilizer application.

Time interval (years)	Soil organic matter (%)	Grain yield (kg·ha ⁻¹)		Increase of grain yield due to the application of 200 kg FDA ha ⁻¹ (kg·ha ⁻¹)
		without FDA [†]	with 200 kg·ha ⁻¹ from FDA	
1 - 5	4.80	3450	4674	1224
6 - 10	4.65	3348	4594	1246
11 - 15	4.21	3034	4349	1315
16 - 20	3.39	2377	3834	1457
21 - 25	3.67	2613	4019	1406
26 - 30	3.70	2638	4038	1400

[†]FDA = diammonium phosphate.

When diammonium phosphate is not applied, the average corn yields decreased from 3450 kg·ha⁻¹ in the period of 1 to 5 years to 2543 kg·ha⁻¹ in the periods of 16 to 30 years, that is 907 kg·ha⁻¹ in a period of 15 years, which would be attributable to the decrease in soil organic matter, from 4.80% to 3.59% in those periods, respectively, that is, 1.21%. A soil organic matter content, of the order of 3.59% in the periods of 16 to 30 years, is usually classified as rich [37] and can make important contributions of nitrogen to the crop [38]. Therefore, the quality of organic matter may be involved in the effect of the decrease in organic matter to values of 3.59% on corn yield, since it is a monoculture of corn.

With the application of 200 kg·ha⁻¹ of diammonium phosphate, which provides 36 kg N ha⁻¹ and 92 kg P₂O₅ ha⁻¹, there was: on the one hand, an increase in corn yields, from 3450 to 4674 kg·ha⁻¹ in the period from 1 to 5 years, that is 1224 kg·ha⁻¹, and from 2542 to 3963 kg·ha⁻¹ in the period from 16 to 30 years, that is 1421 kg·ha⁻¹; and, on the other hand, a decrease in yields, from 4674 kg·ha⁻¹ in the period from 1 to 5 years to 3963 kg·ha⁻¹ in the period from 16 to 30 years, that is, from 1421 kg·ha⁻¹. In these terms, although 200 kg·ha⁻¹ of diammonium phosphate increased yields in relation to non-application, they were not sufficient to compensate for the decrease in yields due to the decrease in soil organic matter, of the order of 711 kg·ha⁻¹, in the event that this was possible with applications of only diammonium phosphate since this fertilizer does not contain other nutrients, in addition to nitrogen and phosphorus, which could be contributing organic matter.

4. Conclusions

In Luvisoles of the State of Campeche:

- The organic matter of the soil decreased in the temporary maize system, from the natural forest system of previous forest up to 16 to 30 years of continuous cultivation, a period in which a balance in the soil apparently appeared. This decrease in the organic matter content of the soil was manifested in a de-

crease in corn grain yield.

- The incorporation of organic waste into the soil (weeds and crop residues) of the previous cycle as usual practice, increased the organic matter of the soil in relation to non-incorporation.
- The decrease in soil organic matter caused a decrease in the yield of unfertilized corn.
- The application of 200 kg·ha⁻¹ of diammonium phosphate (with a contribution of 36 kg N ha⁻¹ and 92 kg P₂O₅ ha⁻¹) increased the yields in rainfed maize system; however, it did not compensate for the decrease in yields caused by the decrease in soil organic matter.

Conflicts of Interest

The authors declare that they have no conflicts of interest with respect to the publication of this document.

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