

Residual soil due to extraction for brick and corn productivity

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Abstract

The extraction of large volumes of soil from agricultural land can have implications for crop production. The objective was to determine the area of agricultural land affected by the extraction of soil for brick manufacturing, the volume extracted, and the effect it has on corn yield in the locality of Santa María Zacatepec, Puebla, in 2022. To do this, plots were georeferenced and the volume extracted and income from sale were calculated; three sites were selected, one undisturbed (Undsoil), another that has undergone soil extraction for more than 12 years (Soildis12), and one that has undergone recent extraction (Soilrecdis) to evaluate the effect on corn yield. All the three sites were planted with the HS-2 corn hybrid to evaluate the response to the factors N, P₂O₅, K₂O and population density integrated into a central composite, rotatable matrix with almost homogeneous information. In the locality, 25.2% of the area has been affected by soil extraction; on average, 33 354.4 m³ ha⁻¹ is extracted, which generates a net income of 555 918.30 \$ ha⁻¹. Corn yield decreased by 79.1% in the remaining soil, with a loss of 52.20 cents per peso invested. The results show that it is possible to recover soils affected by extraction by applying organic matter.

Keywords:

brick manufacturing, soil degradation, soil loss.



Introduction

Soil is one of the most important resources for the production of any crop; its degradation affects productivity. The brick-manufacturing industry extracts large volumes of agricultural land, which impacts agricultural production (Das, 2015; Islam *et al.* , 2017). In Mexico, this phenomenon prevails in brick-producing areas, such as the state of Puebla, where there are approximately 4 500 kilns for brick production that demand a large amount of land (INECC, 2016, 2018). The brick-manufacturing industry is located in the Puebla-San Martín Texmelucan corridor, has contributed to the family economy since pre-Hispanic times (Shadow, 1992), and currently supports a large number of families in rural localities (Ortiz *et al.* , 2020).

The soils used for brick manufacturing are good quality lands for agricultural activity; according to Bahena-Martínez *et al.* (2019), the extraction of soil for brick production leaves infertile land, with no value for agricultural production. In this corridor, the main crop is corn, the profitability of which is low due to high production costs (Alvarado *et al.* , 2018). The low profitability of crops has caused producers to look for other alternatives to obtain income, one of them is to sell the soil for brick manufacturing, affecting agricultural production. In the study region, there is not enough information on the affected area and the effect soil extraction has on agricultural activity, specifically on corn production.

The research aimed to determine the area of agricultural land affected by the extraction of soil for brick manufacturing, the volume extracted, and the effect it has on corn yield, as well as to determine the feasibility of recovering the affected soils in the locality of Santa María Zacatepec, Puebla, located in the Puebla-San Martín corridor.

Materials and methods

The study was conducted in 2022 in the locality of Santa María Zacatepec, municipality of Juan C. Bonilla, Puebla, located at 19°06' north latitude and 98° 20' west longitude at 2 180 masl. The research was developed in two stages; in the first, the affected area and volume of soil extracted were evaluated, and all the farms were georeferenced (Garmin eTrex Venture GPS). The depth was measured with a level staff and the internal contour of the perimeter was followed at each excavated site. The information obtained was interpreted with the Arc View 3.3 software, vector chart E14B42, orthophotos E14B42C and F from 1993, and the geographical synthesis of the state of Puebla in digital format.

In the second stage, three experiments were established under rainfed conditions; one in a soil that has undergone recent extraction (Soilrecdis), another in a soil that has undergone extraction for more than 12 years, has been sown each year, and has received bovine manure (Soildis12), and the third in a soil without extraction (Undsoil). In the experiments, corn (HS-2 hybrid) was planted to explore the factors N, P₂O₅, K₂O and population density (PD). The exploration levels were: from 100 to 180 kg for N, from 20 to 100 kg for P₂O₅, from 0 to 80 kg for K₂O and PD of 40 and 80 000 plants ha⁻¹.

The fertilization sources used were Urea (46% of N), Diammonium phosphate (18% of N plus 46% of P₂O₅) and Potassium chloride (60% of K₂O). One third of the N, all phosphorus, and all potassium were applied at sowing; the remaining N was applied 50 days after sowing. The fertilization and population density treatments were integrated into a central composite, rotatable matrix with almost homogeneous information, divided into thirds (Cochran and Cox, 1957). The experimental unit consisted of four furrows six meters long and 0.9 m wide. Harvesting was done manually, including plants with full competence in the two central rows of each experimental unit.

Per experiment, a soil sample was taken from the first 30 cm deep, which was formed by 15 subsamples; each sample was subjected to the determination of extractable phosphorus (P) by the Bray-1 method; exchangeable potassium (K), calcium (Ca) and magnesium (Mg) by the Peech-Morgan method; organic matter by the modified Walkley and Black wet combustion method; pH

in a soil-to-water ratio of 1:2; percentage of sand (San), silt (Sil) and clay (Cla) by the hydrometer method modified by Day and bulk density.

The yields by experimental site were analyzed by regression with the maximum increase of R (MAXR) procedure of SAS, considering the general quadratic model as a basis. With the equations obtained by experimental site, the optimal economic treatment for unlimited capital and the maximum yield were estimated, with the costs shown in Tables 1, 2 and 3.

Table 1. Costs of inputs used in the soil study to determine extraction and corn productivity.

Item	Nitrogen	P ₂ O ₅	K ₂ O	\$ of 1 000 seeds
	(\$ kg ⁻¹)			
Amount	26.09	36.96	28.17	26.67
Transport	0.40	0.40	0.40	0.01
Application or sowing	1.16	1.16	1.16	7.50
Capital cost	6.76	9.41	7.22	8.35
Net cost	34.40	47.93	36.78	42.53

Table 2. Price of corn grain and cost of harvesting used in the soil study to determine extraction and corn productivity.

Item	(\$ t ⁻¹)	Capital cost (\$)	Net cost (\$)
Market price	6 278	-	-
"Mowing, harvesting and sacking"	625	49.70	674.70
Shelling	150	11.93	161.93
Transport to the house	120	9.543	129.54
Transport to the market	160	12.72	172.72

Table 3. Fixed costs and corn production used in the soil study to determine extraction and corn productivity.

Item	(\$ ha ⁻¹)	Capital cost (\$)	Net cost (\$)
Fallowing cost	2 000	488.79	2 488.79
Harrowing cost	1 400	342.13	1 742.13
Task cost	1 400	342.13	1 742.13
Cost of pesticides and application	2 200	537.63	2 737.63

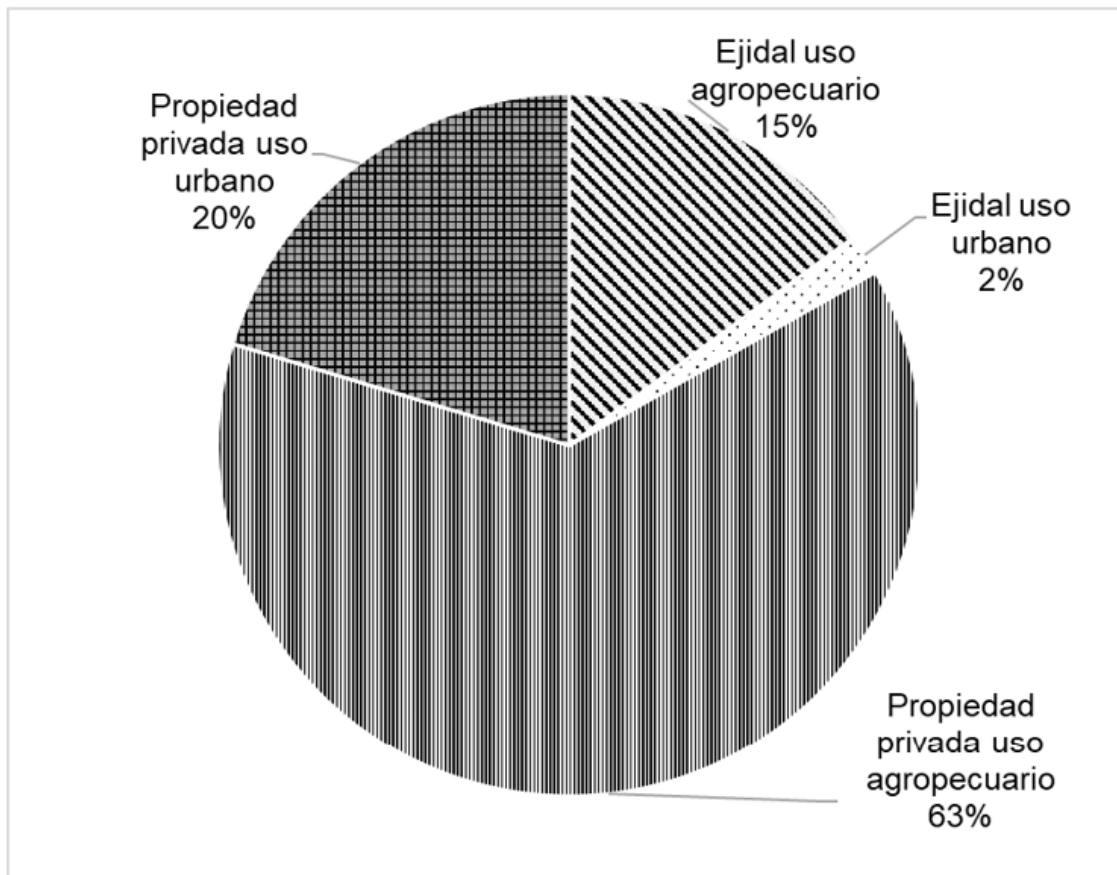
Results and discussion

Soil use and analysis

The locality possesses 1 512 485 ha, 22% under urban use, and the rest (78%) is occupied by agricultural activity, of which 228.8 ha is ejido land and 948.7 ha is private property (Figure 1).



Figure 1. Land tenure and type of property of the locality of Santa María Zacatepec, municipality of Juan C. Bonilla, Puebla.



The locality' soils are considered very productive (CIMMYT, 1974), they are Fluvisols and Regosols with characteristics suitable for brick manufacturing (FAO/UNESCO, 1988). Gupta and Narayan (2010); Das (2015) mention that the production of red brick requires soils with a clayey, silty texture and loam, clayey loam, or silty loam soil, characteristics similar to the soils of the study locality. Table 4 shows the physical and chemical characteristics of the experimental soils; the soils disturbed by extraction experienced a decrease of 69.7, 84, 66.6 and 29% in Mg, K, P, and organic matter (OM), respectively, between Undsoil and Soilrecdis; in contrast, between Undsoil and Soildis12, the decrease was 68.2, 90.6 and 12.6% in Mg, K, and P, respectively, but the OM increased by 55.8% due to the addition of manure that the producer made year after year.

Table 4. Chemical and physical properties of the soils of the experimental sites.

Site	pH	BD (g cm ⁻³)	Ca (Cmol(+) kg ⁻¹)	Mg (Cmol(+) kg ⁻¹)	K Cmol(+) kg ⁻¹	OM (%)	P (mg kg ⁻¹)	San (%)	Sil (%)	Cla (%)
Soilrecdis	7.21	1.31	10.27	1.14	0.68	0.36	2.56	53.12	26.75	20.13
Soildis12	6.32	1.24	7.85	1.13	0.4	0.79	6.7	55.62	19.98	24.4
Undsoil	6.28	1.19	4.3	3.55	4.26	0.507	7.67	57.21	17.18	25.61

BD= bulk density; OM= organic matter.

For calcium, bulk density, and pH, the values were higher in the disturbed soils. In this regard, Khan *et al.* (2007); Siddique *et al.* (2014); Das (2015) point out that physicochemical properties, fertility, soil biota, and productivity are altered when soil is extracted for brick manufacturing.

Soil extraction

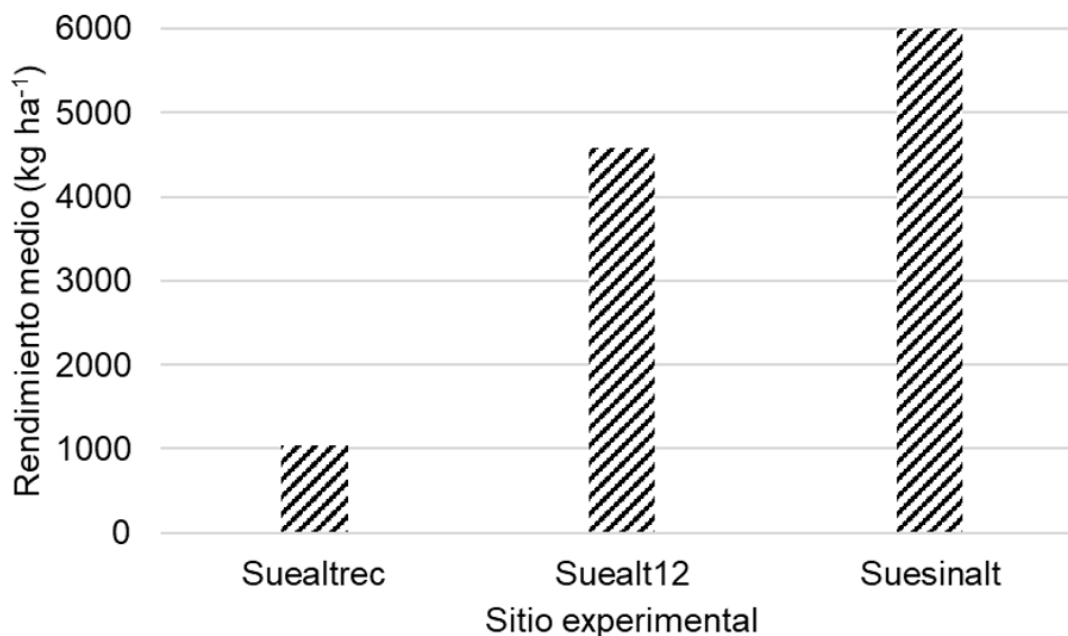
Soil extraction ($12\,687\,223\text{ m}^3$) in Santa María Zacatepec has affected $380\,376\text{ ha}$ (25.2% of the total area); 99% of the area is private property. The volume of extraction varies by farm, depending on the economic needs of the producer or the conditions of the land. The extraction depth ranges from one to seven meters, with a predominance of 4, 5 and 3 m strata, covering 77.1% of the affected area. On average, $33\,354.4\text{ m}^3\text{ ha}^{-1}$ has been extracted, which has generated a net income of $555\,918.30\text{ \$ ha}^{-1}$, which can be attractive for the producer, since once the soil is extracted, they keep the land and continue cultivating it and others abandon it (most of the producers), waiting for the opportunity to sell it. Bahena-Martínez (2019) reports an extraction of $21\,384\,000\text{ t}$ of soil per year to produce $7\,128\,000$ bricks in Coyuca de Benítez, Guerrero.

Low crop production is the main reason for extracting the soil. On the other hand, young people who have inherited the land sell it, they temporarily migrate to other states and abroad (García and Núñez, 2007). Biswas *et al.* (2018) found that producers sell soil for brick manufacturing due to economic difficulties. In the locality, in the soils that have undergone extraction and are not cultivated, weeds grow, and garbage and/or rubble is deposited; this coincides with Barrow (1991), who pointed out that the soils that have been subject to extraction for bricks are abandoned and waste is deposited in them.

Effect on soil productivity

The undisturbed land (Undsoil) exceeded the corn grain yield of the soil that has undergone recent extraction (Soilrecdis) by 79.1% and that of the soil that has been subject to extraction for more than 12 years (Soildis12) by 20.4% (Figure 2). It is important to note that, as Zhang and Fang (2007) indicate, when topsoil is removed for brick manufacturing, crop productivity decreases.

Figure 2. Average yield of corn grain by experimental site.



On the other hand, it is inferred that, with the addition of manure, the productive capacity of the lands where soil has been extracted can be recovered, as happened at the Soildis12 site, where the corn yield was less affected than in the Soilrecds. In this regard, by adding organic matter to the soil, Crespo (2009) recovered the physical, chemical, and biological properties of soils. The regression equations for grain yield by experimental site obtained with the MAXR procedure of SAS are shown in Table 5.

Table 5. Functions of grain yield response to study factors by experiment.

Experiment	Model	MSE	R ²	Prob>F
Soilrecds	$Y=1171.0556+26.79167n-25.7083p+41.875np+47.0nk+21.0625nd-39.125pd-27.875npk-34.438nkd-49.847n^2-46.4097p^2-49.597k^2-39.347d^2$	9 826.389	0.6432	<0.0001
Soildis12	$Y=5344.889+323.521n-150.896k-279.531np-8.593nk+174.031kd-105.843nkd-422.3n^2-84.363p^2-142.738k^2-97.613d^2$	235 303	0.7201	<0.0001
Undsoil	$Y=7009.722+347.1796n-224.0129p-167.679d-173.106nk-311.606nd-124.0194pk-148.768pd-281.956knd-154.393pkd-195.079n^2-423.829p^2-351.329k^2-449.517d^2$	194 919	0.8499	<0.0001

MSE= mean square of the error of the regression model, n= (N-140)/40; p= (P-80)/40; k= (K-60)/30; d= (PD-50)/10.

The regression models (Table 5) explain 64.3, 72 and 85% of the variation in grain yield for Soilrecds, Soildis12 and Undsoil, respectively. It can be estimated that when the variables n, p, k, and d take values of zero, a corn grain yield of 1 171, 5 344.5 and 7 009.7 kg ha⁻¹ is obtained in Soilrecds, Soildis12, and Undsoil, respectively. This indicates low soil productivity due to loss of nutrients such as potassium, phosphorus and organic matter (Table 4). Cotler *et al.* (2020) found that, by degrading the top layer of agricultural soils, up to 81% of corn production is lost.

The optimal economic treatment (OET) was 63.6 and 44.8 cents per peso invested in corn production in Undsoil and Soildis12, respectively (Table 6); for Soilrecds, 52.2 cents per peso invested was lost. In Soilrecds, there was a decrease of 5 938 t ha⁻¹ of corn and when applying the costs of the OET in Undsoil, 25 869.00 \$ ha⁻¹ year⁻¹ was lost. Biswas *et al.* (2018) found a 40-80% reduction in crop production, and 40-70% reduction in income due to soil extraction for brick manufacturing in Bangladesh.

Table 6. Optimal economic treatments (N-P₂O₅-K₂O-PD), expected grain yields, net income, and benefit-cost ratio (B/C) of corn grain by experimental site.

Site	n	p	k	pd	N	P	K	PD	Y	NI	B/C
Soilrecds	-2	-2	-0.2	-1.7	100	20	0	43	1 223	-8 384	-0.52
Soildis12	0	-0.3	-0.2	-0.2	140	54	0	40	5 346.8	10 388.2	0.44
Undsoil	0.8	-0.5	-0.4	-0.5	156	50	32	55	7 161	17 483.8	0.63

n, p, k, pd= variables encoded for N, P, K, PD; Y= yield; NI= net income.

The maximum yields are presented in Table 7. It was estimated that 349 and 495% higher grain yields were obtained in Soildis12 and Undsoil, respectively, compared to Soilrecds.

Table 7. Maximum expected corn grain yields, fertilization treatments (N-P₂O₅-K₂O-PD), net income, and benefit-cost ratio (B/C) by experimental site.

Site	n	p	k	pd	N	P	K	PD	Y	NI	B/C
Soilrecds	-2	-1.8	-2	-1.4	100	24	0	46	1 231.2	-8 607.6	-0.527
Soildis12	0.5	-0.2	-1	-0.6	150	56	20	54	5 523.6	9 552.8	0.38
Undsoil	1.4	-0.2	-0.1	-0.6	168	56	38	54	7 327.1	17 536.7	0.616

n, p, k, pd= variables encoded for N, P, K, PD; Y= yield; NI= net income.

The maximum yield in Soilrecdis is very close to or at the lowest evaluated level of each factor, despite the fact that there are higher levels, perhaps due to the physical, chemical, and biological conditions of the land where the upper layers of soil have been extracted, which have been greatly disturbed (Andraski and Lower, 1992; Lal, 2008), which causes loss of nutrients and they are not used by the crop, which reduces yield (Pimentel, 2006; Bullock *et al.*, 2017). Although the land produces food for the family's diet, it is more attractive for the producer to sell the soil for brick production since they obtain 555 918 \$ ha⁻¹ on average.

The producers who sell the soil for brick manufacturing are mainly engaged in selling labor in local factories. The producer, through the sale of soil, temporarily resolves an economic situation, but if there is no reconversion of production, they will have a sterile soil that cannot be used for agricultural activities. Soil degradation has led to a decrease in the productivity of crops and has increased production costs due to higher nutrient requirements, as Huitzhusen (1993) points out.

The results obtained show that, in part, it is feasible to recover the soils affected by extraction by adding organic matter and it is suggested to implement a soil recovery program to reintegrate them into agricultural activity, in addition to finding other alternatives for brick manufacturing.

Conclusions

Soil extraction affects good quality agricultural land allocated to production in the locality of Santa María Zacatepec, Puebla, and reduces the yield of corn grain, which can continue to lead to low profitability in the crop. It is feasible to recover the soils affected by extraction for brick manufacturing by adding organic matter.

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