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Article

Curvas de retención de humedad y modelos de pedotransferencia en un Andosol bajo distintos usos de suelo

Moisture retention curves and pedotransfer models in Andosol under different land uses

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Resumen:

La presente investigación tuvo por objetivos conocer el comportamiento de la capacidad de retención de humedad de un Andosol con presencia de diferentes usos de suelo: forestal y agrícola (aguacate convencional, aguacate orgánico y macadamia); determinar la capacidad de campo (*CC*), el punto de marchitez permanente (*PMP*) y el agua disponible (*AD* [*CC-PMP*]); y validar seis funciones de pedotransferencia para *CC* y *PMP*. La curva de retención de humedad (*CRH*) se aplicó por medio del método de la placa y membrana de presión a distintas tensiones: 33 (*CC*); 50, 150, 500, 1 000 y 1 500 ([*PMP*] KPa), mediante extractores de placa en muestras recolectadas a dos profundidades (0-20 y 20-40 cm). Los resultados demuestran que existen diferencias significativas entre usos de suelo y tensiones. La *CC* registró valores en un intervalo de 55.95 a 69.03 %, con un *PMP* entre 33.54 a 45.66 % en la profundidad 0 - 20 cm; y de 40.99 a 62.02 %, con 25.27 a 36.89 % de *PMP* a una profundidad de 20 - 40 cm. De acuerdo a los resultados, la *FPT* que presentó la mayor capacidad de predicción para la estimación del contenido de agua fue la de *Rawls* y *Brakensiek*. El cambio de uso del suelo de terrenos forestales a cultivos agrícolas modifica la capacidad de un Andosol para retener humedad.

Palabras clave: Agua disponible, Andosol, capacidad de campo, funciones de pedotransferencia, punto de marchitez permanente, uso de suelo.

Abstract:

The purpose of this research was to determine the behavior of the moisture retention capacity of an Andosol considering different land uses (forestry and agricultural (conventional avocado, organic avocado and macadamia)), and to determine the field capacity (*CC*), the permanent wilting point (*PMP*) and the available water (*AD* [*CC-PMP*]), as well as to validate six pedotransfer functions for *CC* and *PMP*. The moisture retention curve (*CRH*) was applied with the pressure plate and pressure membrane method at different voltages: 33 (*CC*); 50, 150, 500, 1 000 and 1 500 ([*PMP*] kPa), using plate extractors on samples collected at two different depths (0-20 and 20-40 cm). The results show that there are significant differences between land uses and between tensions. The *CC* registered values ranging from 55.95 to 69.03 %, and the *PMP*, values between 33.54 and 45.66 % at a depth of 0-20 cm, and of 40.99 to 62.02 % and 25.27 to 36.89 % at a depth of 20-40 cm, respectively, for an Andosol. According to the results, the *FPT* that exhibited the greatest predictive capacity for the determination of water content was that of Rawls and Brakensiek. The change of land use from forest land to agricultural crops modifies the moisture retention capacity of Andosols.

Key words: Available water, Andosol, field capacity, pedotransfer functions, permanent wilting point, land use.

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Introduction

The moisture retention curves (*CRH*) of the soil express the existing relationship between the moisture content and its matrix potential, and reflect the water retention capacity of the soil in terms of suction; this relationship depends on the factors associated with the porosity of the soil (Teepe *et al.,* 2003; López *et al.,* 2013; Yáñez *et al.,* 2015; Casanova, 2018).

The properties of Andosols are very complex, due to their high content of sand. According to Torrealba (2008), sandy soils release a large amount of water at very low pressures, as they have a high porosity and low densities, which renders them more susceptible to moisture loss.

The soils of forest plots which have been modified to an agricultural use exhibit alterations in their structure that lead to a degradation process and directly affect the water retention capacity (Meza and Geissert, 2006). However, the type and intensity of the cultures define the level of this impact on the hydrological properties.

Studies on the indirect determination of field capacity (*CC*), permanent wilting point (*PMP*) and available water (*AD*) in the Andosols are scarce; however, certain PedoTransfer Functions (*FPT*) have been developed for estimating these properties based on other variables, such as organic matter (*MO*), bulk density (*DA*) and sand (*A*), silt (*L*) and clay (*R*) content (Rawls and Brakensiek*,* 1985; Delgado and Barreto, 1988; Malavé, 1991; Pecorari, 1988; Peralta and Barrios, 2006; Chicas *et al.,* 2014).

The soil-water-use relationship is represented by the moisture retention capacity, which is essential to know in order to understand the hydraulic processes that occur in the soil. Its direct determination requires much time and is costly, as it demands a large number of samples, due to the high spatial and temporal variability of the hydraulic properties of the soil. An alternative is the use of *FPT* models, which estimate the *CRH* based on easily measurable properties, although the prediction depends on the sample size, as well as on the characteristics of the soil (Pineda and Viloria, 1997; Medeiros *et al.,* 2014; Souza *et al.,* 2016).

The culture of avocado in the state of *Michoacán* has triggered economic growth; however, this progress has also accelerated the deforestation and land use change processes, from its specific (climate and soil) needs, which coincide with those of the forest ecosystems. This has brought about the loss of soils and the modification of their hydrological properties (Chávez *et al.,* 2012).

It is essential for agriculture to maintain adequate levels of water in the soil, as this ensures the success of the crops, and it is crucial in forest ecosystems, because of the multiple environmental services that they provide (Taboada and Micucci, 2002; Chicas *et al.,* 2014).

The objective of the present research was to estimate the behavior of the moisture retention capacity in an Andosol at different tensions, by determining the *CC*, *PMP*, and *AD*, using the *CRH* and *FPTs* in order to assess the effect of land use change from a forest system to the culture of (organic and conventional) avocado (*Persea americana* L.) and macadamia (*Macadamia integrifolia* Maiden & Betche).

Materials and Methods

Study area

The study was carried out in the *Toreo El Alto ejido*, in *Uruapan* municipality, *Michoacán*; located in the Transversal Neovolcanic Axis, between 19°28’22.2’’ N and 102°00’19.7’’ W. This area belongs to the *Balsas* river region, at an altitude of 1 890 m; the climate is temperate humid, with summer rains (Cw) (García, 2004), with an annual mean temperature range of 10 and 27 °C and has an annual mean precipitation above 1 500 mm. The soil type is volcanic Andosol (Alcalá *et al*., 2001).

Soil sampling

Four plots on an Andosol with different land use were selected: one forest plot and three agricultural plots (for the culture of conventional avocado, organic avocado and macadamia). Four samples consisting of approximately 2 kg were collected from each, at two different depths (0-20 and 20-40 cm) and transported to the Soils Laboratory of the Graduate School of Forest Sciences of the of the *Universidad Autónoma de Nuevo León* for further analysis.

Determining the moisture retention capacity

The 32 collected samples were dried in the open air and sifted in a 2 mm sieve. *CRH* was determined by the pressure plate and pressure membrane method with disturbed samples (Yáñez, 2017).

Rings with a 10 cm diameter were placed on the plate; the samples were subsequently saturated in water during 12 hours and were subjected to different pressures: 33, 50, 150, 500, 1 000 and 1 500 kPa in pressure plate extractors (Soil Moisture Equipment Corp.). They were subsequently dried during 24 hours at a temperature of 105 °C, and the soil moisture was determined using the AS-05 method of the NOM-021-RECNAT-2000 (Semarnat, 2002).

$$\theta g = \frac{(PB + Psh) - (PB + Pss)}{(PB\ + Pss) - (PB)} * 100$$

Where:

θg = Moisture content (%)

PB = Weight of the container with a lid (g)

Psh = Moist soil weight

Pss = Dry soil waste (g)

$PB + Psh$ = Weight of the container plus weight of the moist soil (g)

$PB + Pss$ = Weight of the container plus weight of the dry soil (g)

CRH, *CC* (33 kPa), *PMP* (1 500 kPa) and *AD* were estimated using the values thus obtained (difference between *CC* and *PMP*).

Complementary variables for determining *FPTs*

Complementary variables are generally utilized for estimating the *FPTs*, based on a true, acceptable foundation; in this case, the *MO* content was determined using the method of Walkley and Black modified by Woerner (1989); the texture was determined by using the Bouyoucos hydrometer method, based on the AS-09 technique of the NOM-021-RECNAT-2000 (Semarnat, 2002); and the *DA* (g cm^{-3}) was determined by using the gravimetric method (Woerner, 1989).

Pedotransfer functions (*FPT*)

There are numerous pedotransfer equations generated from edaphological variables, with which mathematical models have been developed in order to determine the *CC* and *PMP*.

Water retention was estimated by a collection of mathematical functions from various researches (tables 1 and 2), in order to obtain the *CC* (33 kPa) and the *PMP* (1 500 kPa).

Table 1. Regression equations for determining the moisture content at 33 kPa (*CC*).

Model	**Functions**
Rawls and Brakensiek, 1985	$\theta = 0.026 + 0.005 * R + 0.0158 * MO$
Delgado and Barreto, 1988	$\theta = 16.55 - 0.174 * A - 0.164 * L + 0.154 * R + 1.24 * MO$
Pecorari, 1988	$\theta = 4.04 + 0.252 * R + 0.206 * L$
Malavé, 1991	$\theta = 16.1608 - 0.1877 * A + 1.0528 * MO$
Peralta and Barrios, 2006	$\theta = 15.691 + 0.566 * A + 0.092 * L + 1.787 * MO - 8.412 * DA$
Chicas *et al.,* 2014	$\theta = 55.05 - 28.97 * DA - 0.23 * R$

θ = Moisture content; *A* = Sand; *L* = Silt; *R* = Clay; *MO* = Organic matter; *DA* = Bulk density.

Table 2. Regression equations for determining the moisture content at 1 500 kPa (*PMP*).

Model	Functions
Rawls and Brakensiek, 1985	$\theta = 0.2576 - 0.002 * A + 0.0036 * R + 0.0299 * MO$
Delgado and Barreto, 1988	$\theta = 29.06 - 0.290 * A - 0.253 * L + 0.135 * R + 2.56 * MO$
Pecorari, 1988	$\theta = 6.85 + 0.360 * R + L$
Malavé, 1991	$\theta = 23.953 - 0.2228 * A + 4.6436 * MO$
Peralta and Barrios, 2006	$\theta = 5.387 + 0.469 * A - 0.020 * L + 0.6909 * MO - 4.949 * DA$
Chicas *et al.,* 2014	$\theta = 67.3 - 33.77 * DA - 0.23 * R$

θ = Moisture content; *A* = Sand; *L* = Silt; *R* = Clay; *MO* = Organic matter; *DA* = Bulk density.

Statistical analyses

Normality tests were applied to the moisture retention capacity. Since the data did not comply with the normality, the Kruskal-Wallis non-parametric test was used (Berlanga and Rubio, 2012) in order to verify the existence of significant differences in the water content at different tensions between land uses.

Validation of pedotransfer functions

The mean squared error (*CME*) was estimated in order to validate the fitness of the models, based on the following expression (Patil and Singh, 2016):

$$CME = \sum (Z^*i - Zi)^2/n$$

Where:

Z^*i = Moisture retention value estimated for the validation sample *i*

Zi = Real value for the same sample

n = Total number of validation samples (n=32)

CME allows measuring the error when calculating the moisture content with the regression equation. In addition, the determination coefficient (R^2) —which establishes the quality of the model for replicating the results— was estimated (Patil and Singh, 2016).

Results and Discussion

Moisture retention capacity (*CRH*)

The Kruskal-Wallis test shows significant differences between the land uses assessed at different tensions and depths. According to Daza *et al.* (2014), the changes in the cover generate loss of soil moisture; this impact is reflected by the results obtained in the present research (Table 3). In general, all types of agricultural practices cause a loss of cover in a given time period, with the resulting exposure of the soil to the air and the increased evaporation on its surface.

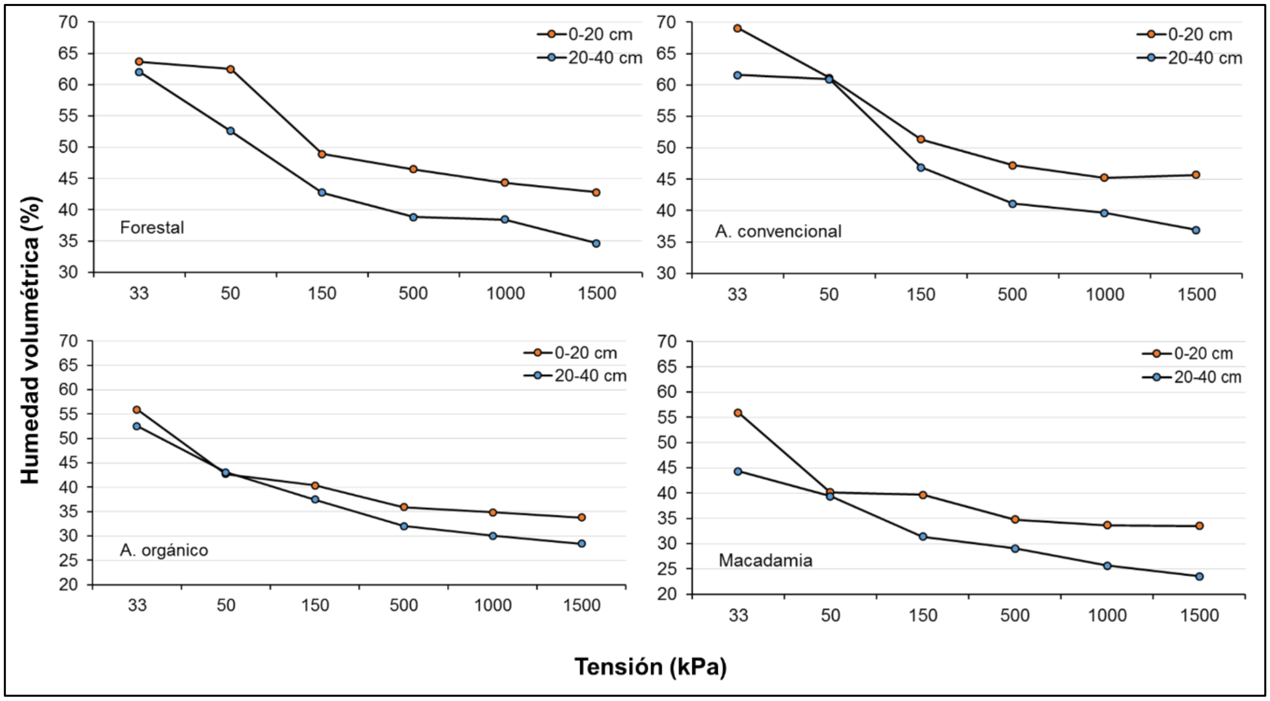
Table 3. x^2 values, according to the Kruskal-Wallis test for different intervals between tensions and mean values (*n*=4) in the studied land uses.

	Water retention tension kPa					
	33	**50**	**150**	**500**	**1 000**	**1 500**
0-20 cm						
X^2	10.059*	11.294**	11.051*	11.404**	11.404**	11.007*
Forest	63.65	62.47	48.88	46.45	44.33	42.79
Conventional avocado	69.04	61.15	51.36	47.19	45.22	45.66
Organic avocado	55.95	42.72	40.39	35.96	34.87	33.78
Macadamia	55.95	40.18	39.7	34.78	33.65	33.55
20-40 cm						
X^2	8.492*	11.801**	13.786**	9.968*	9.992*	10.477*
Forest	62.03	52.57	42.73	38.81	38.42	34.61
Conventional avocado	61.61	60.92	46.84	41.07	39.63	36.89
Organic avocado	52.56	43.05	37.48	32.05	30.04	28.43
Macadamia	44.31	39.41	31.43	29.03	25.65	23.52

*= Significant difference (P≤0.05); ** = Highly significant difference (P≤0.01).

Musso and Suazo (2019) relate it to the distribution of mineral particles (size), specifying that sandy soils are more permeable, unlike the silts and clays, which retain a larger amount of water.

The moisture retention curves show that the land use for the culture of macadamia exhibited the lowest moister content at both depths, unlike the use for the culture of conventional avocado (Figure 1), which depends on the texture. The results indicated 50 to 70 % of sands in macadamia, and 30 to 40 % in conventional avocado (Table 4).



Humedad volumétrica = Volumetric moisture; *Forestal* = Forestal;

A. convencional = Conventional avocado; *A. orgánico* = Organic avocado.

Figure 1. Moisture retention curves at two different depths (0-20 and 20-40 cm) in the different uses of the soil.

Table 4. Mean values ± standard deviation of the data to validate the models (*n*=4).

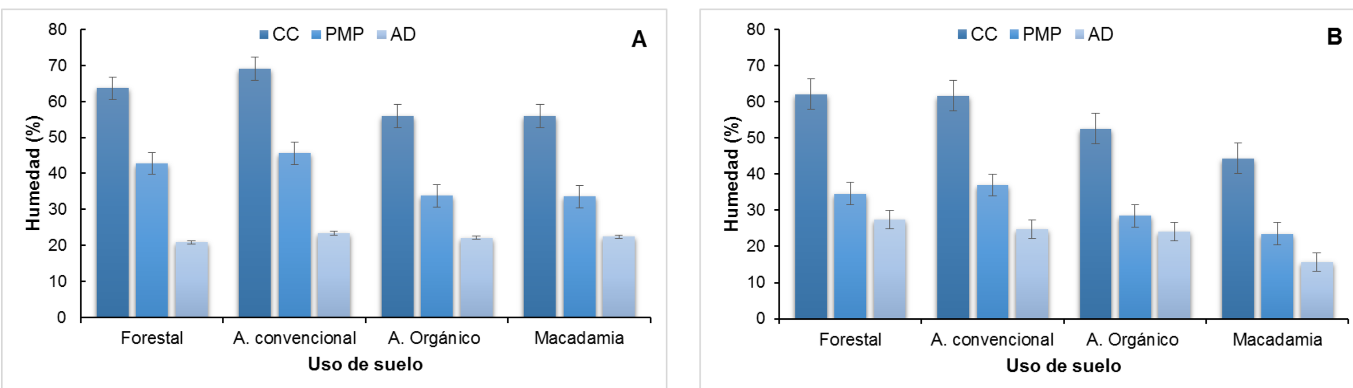
Land use	***MO*** (%)	***DA*** (g cm^{-3})	***A*** (%)	***L*** (%)	***R*** (%)	**Texture**
0-20 cm						
Forest	13.02±1.94	0.56±0.10	48.60±5.89	45.34±6.86	6.06±0.99	CA
Conventional avocado	16.41±1.32	0.57±0.05	27.96±6.00	60.81±5.52	11.23±1.30	*CL*
Organic avocado	9.05±1.20	0.82±0.12	51.10±4.30	42.13±4.29	6.77±1.78	*CA*
Macadamia	13.80±2.32	0.69±0.06	56.46±7.03	37.36±5.77	6.18±1.91	*CA*
20-40 cm						
Forest	6.30±3.10	0.65±0.04	56.28±3.46	37.66±2.92	6.06±2.15	*CA*
Conventional avocado	12.63±0.78	0.59±0.05	37.05±6.48	53.22±7.53	9.73±2.84	*CL*
Organic avocado	5.56±2.61	0.81±0.13	59.14±1.65	32.91±2.63	7.95±1.27	*CA*
Macadamia	6.60±1.67	0.73±0.12	67.82±8.70	27.00±8.08	5.18±1.00	*CA*

MO = Organic matter; *DA*= Bulk density; *A* = Sand; *L* = Silt; *R* = Clay; Texture: *CA* = Loamy sandy; *CL* = Loamy silty.

The forest system registered high water contents at low pressures, with 65 % and 60 % moisture at depths of 0-20 and 20-40 cm, respectively. The organic avocado system started with a 55 and 50 % at depths of 0-20 and 20-40 cm, respectively, and lost 15 % of the moisture content in both conditions.

As depth increases, the moisture retention capacity decreases as a result of the presence of a larger amount of sands. Volverás *et al.* (2016) determined the moisture retention curves and the impact of agricultural management; the authors stated a negative effect on the moisture retention capacity due to the influence of the depth and slope of the assessed areas. In general, the amount of water available in the soil is associated with the *MO* content. Minasny and Mcbratney (2018) document that the increase in the amount of water available for the plants due to an increase in *MO* is uncertain and may be overestimated.

The moisture retention capacity in the forest at *CC* at a depth of 0-20cm was 65 %; for the culture of organic avocado and macadamia, it decreased by 7 and 13 %, respectively, and for the culture of conventional avocado, it increased by 5 %. The same tendency was observed for *PMP* (40 % moisture): in the culture of organic avocado, it diminished by 9 %, in macadamia 12 %, and in the conventional avocado, it increased by 3 % (Figure 2).



Humedad = Moisture; *Uso de suelo* = Land use; *Humedad volumétrica* = Volumetric moisture; *Forestal* = Forestal; *A. convencional* = Conventional avocado; *A. orgánico* = Organic avocado; *CC* = Field capacity; *PMP* = Permanent wilting point; *AD* = Available water.

Figure 2. Moisture constants at two different depths (A: 0-20 cm, and B: 20-40 cm) in an Andosol with different land uses.

The amount of available water is in terms of the *CC* and *PMP*; at the first 20 cm of depth, it was estimated in approximately 20 % for all land uses; at a depth of 20-40 cm, the forest soil use registered an increase up to 30 % (+10 %) in retention capacity; for the rest of the land uses, there was a slight increase of 1 to 2 %, except for the culture of macadamia, which exhibited 15 % reduction in relation to forest use. La Manna *et al.* (2018) researched the water retention capacity in Andosols with different textures and indicated *AD* values of 7 to 15 % in loamy sandy textures, and of 13 to 18 % in loamy silty textures.

Daza *et al.* (2014) obtained a *CC* of 80 % and a *PMP* of 50 % in forests with native vegetation on volcanic soils in Colombia. Meza and Geissert (2006) assessed the stability of Andosols with forest and agricultural use; their results indicate a moisture retention of 50 % at *CC* and 20 % at the *PMP* in plots for forest use, and of 30 and 10 %, respectively, in plots for agricultural use. Chicas *et al.* (2014) report a *CC* of 13 to 40 % and a *PMP* of 8 to 30 % in volcanic soils; these values are considered to be low with respect to the values estimated in the present study for forest use, which were 60 to 70 % at *CC*, and 30 to 45 % at the *PMP* (Figure 2).

Complementary variables for determining *FPTs*

Other variables generally associated to the capacity of the soil to retain water had to be assessed in order to determine the *FPT*. The high *MO* contents at the first depth (0-20 cm), which ranged between 9 and 16 %, stood out; the *DA* was low, with a high content of sands and silts, resulting in a loamy sandy texture for most of the assessed soils (Table 4).

At a depth of 20-40 cm, the *MO* contents diminished noticeably, ranging between 5 and 12 %; the *DA* increased slightly, while the content of sands and the reduction of the content of silts were noticeable. The content of clays was similar at both depths, with values ranging between 5 and 11 %.

Pedotransfer functions (*FPT*)

Table 5 shows the *CME* of the models used for determining the *CC* and the *PMP*. It may be seen that the model of Rawls and Brakensiek (1985) exhibited a low *CME* (*CC* = 241.10 and *PMP* = 210.25), and a high R^2 (0.99), which reflects the fact that this model has the best fit with the slightest bias; the rest of the models had higher *CMEs*: Malavé (1991), followed by Delgado and Barreto (1988) and Chicas *et al*. (2014), to cite just a few.

Table 5. Values of the mean squared error (*CME*) of the pedotransfer functions at *CC* (33 kPa) and *PMP* (1 500 kPa), and coefficient of determination (R^2).

Model	33 kPa	1 500 kPa	R^2
Rawls and Brakensiek (1985)	241.10	210.25	0.99
Delgado and Barreto (1988)	992.05	880.96	0.99
Pecorari (1988)	458.53	737.35	0.96
Malavé (1991)	1 328.03	1 007.69	0.78
Peralta and Barrios (2006)	170.74	120.72	0.39
Chicas *et al.* (2014)	822.32	443.27	0.99

Peralta and Barrios (2006) point out that the best prediction is represented by the coefficient of determination, which shows that the variations are accounted for by the variables defined in the equation.

The coefficient of determination was high for all models, except for that of Peralta and Barrios (2006), with an R^2 of 0.39, which accounts for goodness of fit; therefore, the fit of this model is the least reliable, compared to that of the rest of the models (Table 5).

Pineda and Viloria (1997) used the equations of Rawls and Brakensiek (1985) and Malavé (1915) and obtained *CMEs* of 99.73 and 360.21, respectively, at *CC*, while the values at the *PMP* were 27.19 and 195.09, respectively. Notably, the model of Rawls and Brakensiek (1985) exhibited a low *CME*, just as in the present study. For this reason, it is considered to be one of the best predictors for *CC* and *PMP* estimation in Andosols.

According to Pineda and Viloria (1997), the regression models represent an inexpensive alternative for estimating the moisture retention in the soil; however, their precision depends on the number of samples and variables utilized for determining it. For example, based on only 57 samples, Chicas *et al.* (2014) estimate a coefficient of determination of 0.59 % at *CC* and 0.68 % at the *PMP*, which accounts for the variability of the data observed using the generated models. On the other hand, Peralta and Barrios (2006) obtained an R^2 of 0.83 % at *CC* and 0.70 % at the *PMP* using only 22 samples; in both cases, the variation in field capacity and permanent wilting point is accounted for by the variables used in the generated models (tables 1 and 2).

Conclusions

Land use change from forest to agricultural plots modifies the moisture retention capacity in an Andosol.

The pedotransfer functions represent an alternative for determining the water retention capacity; the bulk density, *MO* and granulometric analysis are the variables that offer greater estimation precision in this type of soils.

The Rawls and Brakensiek equation allows optimal modeling of the moisture conditions of Andosol 0-20 cm and 20-40 cm deep. The effects of land use on the soil resource cause a chain reaction on its physical-chemical properties, as these are directly interrelated.

Conflict of interests

The authors declare no conflict of interests.

Contribution by author

Silvia Janeth Béjar Pulido: field research, statistical analysis, interpretation, structure and design of the manuscript; Israel Cantú Silva: design, interpretation, statistical analysis and editing of the manuscript; María Inés Yáñez Díaz: design, interpretation and analysis of the results obtained, and editing of the manuscript; Erik Orlando Luna Robles: field data collection and processing.

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