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Effect of four tillage methods and two forms of urea placement on physical properties of an Ultisol of savanna sowed with three sesame varieties[1]

Efecto de cuatro métodos de labranza y dos formas de colocación de urea sobre las propiedades físicas de un Ultisol de sabana sembrado con tres variedades de ajonjolí

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Abstract

The main objective of this study was to determine the effect of four tillage systems and placement of urea on water content (WC), bulk density (BD), vacuum relationship (VR) and porosity (P) of an Ultisol of savanna sowed with three sesame varieties (*Sesamum indicum* L.). The experiment was carried out at the Estación Experimental de Sabana de la Universidad de Oriente. The statistical design was a split-plot with special arrangement of the treatments assigned to the main plots, being these, four tillage methods (TM): a) Chisel (C): a pass of chisel plow 30 days before sowing (DBS) and a pass of rotary cultivator 1 DBS, b) Harrow (H): three passes of H at 30, 15, and 1 DBS (conventional method), c) minimum tillage (MT): a pass of rotary cultivator 1 DBS and, d) Chisel + Harrow: a pass of C 30 DBS and three passes of H at 30, 15, and 1 DBS. The subplots were constituted by a factorial arrangement of three varieties (V) viz., 'Glauca', 'Acarigua' and 'Blanca' and two forms of urea placement (FUP), 200 kg/ha 30 days after sowing (DAS): banded into the soil and banded on soil surface, for a total of 24 treatments with three replications. A rate of 500 kg/ha of 12-24-12 was applied at the moment of sowing. The weed control was carried out applying Dual, Linurex and Gramoxone at 2, 0.5, and 3 L/ha respectively 1 DAS, in all the treatments. The soil samples were taken 52 and 99 DAS. The results showed that at the 52 DAS the soil with highest WC was in the plots sowed with 'Blanca'. BD, VR and P were similar in all the TM in the three cultivars. The plots sowed with 'Blanca' presented the lowest BD, the biggest VR and P with the ML, the plots sowed with 'Glauca' and 'Acarigua' presented the lowest BD, a bigger VR

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and P with C and H, while in the method C+H, the plots presented similar BD, VR and P in the three cultivars. At the 99 DAS, for the FUP, the lower BD and larger P were in the plots where urea was placed banded on soil surface. In relation to the TM, the lower BD, the larger VR and P were in the treatments C, C+H and ML.
Key words: Bulk density, water content, porosity, *Sesamum indicum*.

Resumen

El presente estudio tuvo como objetivo principal determinar el efecto de cuatro métodos de labranza y la forma de aplicación de urea sobre el contenido de humedad (CH), densidad aparente (DA), relación de vacío (RV) y porosidad (P) de un Ultisol de sabana sembrado con tres variedades de ajonjolí. El experimento se realizó en la Estación Experimental de Sabana de la Universidad de Oriente. El diseño estadístico utilizado fue el de parcelas divididas con arreglo sistemático de los tratamientos aplicados a las parcelas principales, estando constituidas estas por cuatro métodos de labranza (ML): a) Cincel (C): un pase de arado de cincel 30 días antes de la siembra (DAS) y un pase de rotativa 1 DAS; b) Rastra (R): tres pases de rastra a los 30, 15 y 1 DAS (método convencional); c) Labranza mínima (LM): un pase de rotativa 1 DAS y d) Cincel + Rastra: un pase de arado de C 30 DAS y tres pases de R a los 30, 15 y 1 DAS. Las subparcelas estuvieron constituidas por un arreglo factorial de tres variedades (V): 'Glauca', 'Acarigua' y 'Blanca' y dos formas de colocación de urea (FCU), 200 kg/ha 30 días después de la siembra (DDS): bandas enterrada y superficial, para un total de 24 tratamientos con tres repeticiones. Se aplicó una dosis de 500 kg/ha de 12-24-12 al momento de la siembra. El control de malezas se realizó aplicando Dual, Linurex y Gramoxone a razón de 2; 0,5 y 3 L/ha respectivamente 1 DDS, en todos los tratamientos. Las muestras de suelo se tomaron a los 52 y 99 DDS. Los resultados mostraron que a los 52 DDS el mayor porcentaje de humedad del suelo (HS) se presentó en las parcelas sembradas con 'Blanca'. La DA, RV y P fueron similares en todos los ML bajo los tres cultivares. Las parcelas sembradas con 'Blanca' presentaron una menor DA, una mayor RV y P con la LM, las parcelas sembradas con 'Glauca' y 'Acarigua' presentaron una menor DA, una mayor RV y P con C y R, mientras que en el método C+R , las parcelas presentaron similares DA, RV y P en los tres cultivares. A los 99 DDS, para la FCU, la menor DA y mayor P se encontraron en las parcelas donde se colocó la urea en bandas superficiales, en relación a los ML, la menor DA, mayores RV y P se encontraron en C, C+R y LM.
Palabras claves: Densidad aparente, contenido de humedad, porosidad, *Sesamum indicum*.

Introduction

The agricultural soils of the Mesas Orientales are mainly Ultisols and Oxisols with argilic, oxic and kandic horizons at depths between 50 and 60 cm. Their total porosity ranges between 30 and 40% of the soil volume. The Oxisols' bulk density ranges between 1.30 and 1.50 g/cm^3 in its first 40 cm and in the Ultisols from 1.40 to 2.0 g/cm^3, due to its tendency to the compaction and the type of predominant texture in the first horizons (4). The compaction is the increase of the bulk density, decrease of the macroporosity and increment of the soil mechanical resistance, as a result of loads or applied pressure. The increase of the soil bulk density is in function of the compaction force and of the soil water content. The bulk density increases exponentially when increasing the applied force and when increasing the water content until certain limit, since both factors affect the particles orientation. Among the soil compaction effects there are: increments of bulk density, mechanical resistance, CO_2 concentration and risks for water erosion and reduction of the macroporosity, total porosity, water infiltration, hydraulic conductivity and O_2 concentration (14).

The main objective of the present work was to determine the effect of four tillage methods and the form of urea placement on water content, bulk density, vacuum relationship and porosity of an Ultisol soil of savanna cultivated with three sesame varieties.

Materials and methods

The present work was carried out at the Estación Experimental de Sabana de la Universidad de Oriente, in Jusepín, Monagas State in the rainy season in a sandy loam soil. The statistical design was a split-plot with special arrangement of the treatments assigned to the main plot, being these, four tillage methods: a) Chisel: a pass of chisel plough 30 days before sowing (DBS) and a pass of rotary cultivator 1 DBS, b) Harrow: three passes of harrow at 30, 15, and 1 DBS (conventional tillage), c) minimum tillage: a pass of rotary cultivator 1 DBS, and d) Chisel + Harrow: a pass of chisel 30 DBS and three passes of harrow at 30, 15, and 1 DBS. The subplots were constituted by a factorial arrangement of three varieties (V) viz., 'Glauca', 'Acarigua' and 'Blanca' and two forms of urea placement, 200 kg/ha 30 days after the sowing (DAS): banded into the soil and banded on soil surface, for a total of 24 treatments with three replications. The analysis was carried out by the method of conventional variance and the differences among treatments were detected by Duncan's Multiple Range Test. The used level of probability was 10%. For the case of F's high values of the tillage methods the means are only reported without the application of the Duncan's test.

A rate of 500 kg/ha of 12-24-12 was applied at sowing. The weed con-

trol was carried out applying Dual, Linurex and Gramoxone at 2, 0.5, and 3 L/ha respectively 1 DAS, in all the treatments. Each experimental unit was constituted by three rows of 5 m; spacing was 0.70 m in-row and 0.05 m intra-row. The sampling for the determination of the soil physical properties viz, water content, bulk density, vacuum relationship and porosity, were carried out 52 and 99 DAS to a depth of 0-30 cm, using a Uhland Sampler, equipped with 72 cylinders of known volume, with the purpose of to obtain the whole field samples the same day and to avoid changes under the soil moisture conditions. Plots used in the experiment have been harrowed for several years, generally, three or four passes of harrow per year.

The soil bulk density was calculated by means of the method of sampler of known volume, by means of the formula application:

$$BD = \frac{Mds}{V}$$

Where:
BD = Bulk Density in grams/cubic centimeters, g/cm^3
Mds = Mass of dry soil in grams, g
V = Volume of the sampler cylinder in cubic centimeters, cm^3

The vacuum relationship was calculated from the bulk density and the soil real density estimated in 2.65 g/cm^3, and the application of the following formula:

$$VR = \frac{RD}{BD} - 1$$

Where:
VR = Vacuum Relationship
RD = Real Density of the soil in grams/cubic centimeters, g/cm^3
BD = Bulk Density of the soil in grams/cubic centimeters, g/cm^3

The soil porosity was calculated from the bulk density and the soil real density estimated in 2.65 g/cm^3, and the application of the following formula:

$$P = (1 - \frac{BD}{RD}) * 100$$

Where:
P = Porosity of the soil in percentage, %
BD = Bulk Density of the soil in grams/cubic centimeters, g/cm^3
RD = Real Density of the soil in grams/cubic centimeters, g/cm^3

The soil water content was determined using the same sample extracted with the Uhland Sampler, by means of the gravimetric method. Soil properties of minimum tillage plots were considered as original ones (without tillage).

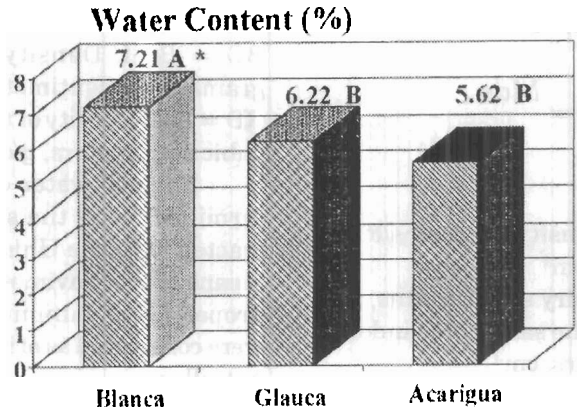
Results

Water content, bulk density, vacuum relationship and porosity of the soil at 52 days after sowing. The analysis of variance indicated significant differences on soil water content for replications and varieties. The co-

efficient of variation was 28.90%. Figure 1 shows Duncan's Test for this character. The greater soil water content occurred in plots cultivated with 'Blanca', while the water content of the plots cultivated with 'Glauca' and 'Acarigua' were statistically similar.

The analysis of variance indicated significant differences for replications, varieties and the interaction varieties * tillage methods for bulk density, vacuum relationship and soil porosity, with coefficients of variation of 4.37; 9.43 and 4.83% respectively. Tables 1, 2 and 3 show the Duncan's Multiple Range Test for these three soil physical parameters. Bulk density, vacuum relationship and porosity were similar in all the tillage methods under the three cultivars. Plots sowed with the cultivar 'Blanca' presented the lowest bulk density, the largest vacuum relationship and porosity with the minimum tillage, the plots sowed with 'Glauca' and 'Acarigua' presented the lowest bulk density and the largest vacuum relationship and porosity with the tillage methods of chisel and harrow; whereas, in the chisel+harrow method plots presented similar bulk density, vacuum relationship and porosity under the three varieties.

Water content, bulk density, vacuum relationship and porosity of the soil at 99 days after sowing. For soil water content and vacuum relationship, the analysis of variance indicated absence of significant differences for all the variation sources: replications, varieties and form of urea placement and its interactions between them and with tillage methods. For soil water content, the general mean was 7.78% and the coefficient of variation was 19.32% and for vacuum relationship, the general mean was 0.80 and



*Means followed by the same letters are not significantly different according to Duncan (P<0.10).

Figure 1. Means for the soil water content (%) at 52 days after sowing of a soil cultivated with three sesame varieties (*Sesamum indicum* L.), in the savanna of Jusepín, Monagas State, in rainy season.

the coefficient of variation was 8.66%. On the other hand, the analysis of variance indicated significant differences on the form of urea placement for the parameters bulk density and soil porosity, with coefficients of variation of 3.72 and 4.78% respectively.

Figure 2 indicates that the smallest bulk density (figure 2A), the largest vacuum relationship (figure 2B) and the largest porosity (figures 2C) occurred in the tillage methods of chisel, chisel+harrow and minimum tillage in comparison with harrow only, although the rigidity of the statistical design of split-plot with special arrangement of the treatments assigned to the main plot does not allow to establish if these differences among different tillage methods are significant or not. The Duncan's test indicated that the smallest bulk density (figure 3A) and the biggest porosity (figure 3B) occurred in plots where urea was applied banded on soil surface in comparison with banded into the soil.

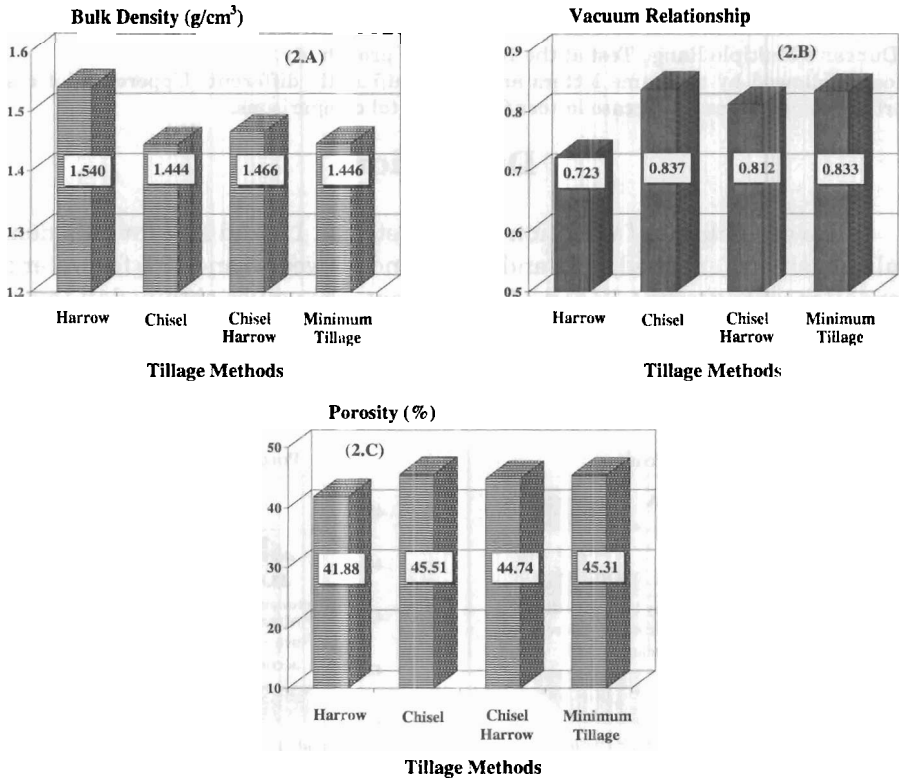


Figure 2. Means for bulk density (g/cm³) (2.A), vacuum relationship (2.B) and porosity (%) (2.C) at 99 days after sowing of a soil under four tillage methods in the savanna of Jusepín, Monagas State, in rainy season.

Table 1. Means for the bulk density (g/cm³) 52 days after sowing of a soil cultivated with three sesame varieties (*Sesamum indicum* L.) under four tillage methods in the savanna of Jusepín, Monagas State, in rainy season.

Tillage Methods	Bulk Density (g/cm³)†		
	Sesame varieties		
	Glauca	Acarigua	Blanca
Chisel	1.374^{Ab}	1.376^{Ab}	1.463^{Aa}
Chisel+Harrow	1.381^{Aa}	1.401^{Aa}	1.434^{Aa}
Minimum Tillage	1.386^{Aa}	1.398^{Aa}	1.317^{Bb}
Harrow	1.360^{Ab}	1.381^{Ab}	1.459^{Aa}

† Duncan's Multiple Range Test at the 10% level of probability.
Means followed by the same letters are not significantly different. Uppercase letters for vertical comparisons, lowercase letters for horizontal comparisons.

Discussion

The coefficients of variation for bulk density determined at 52 and 99 days after sowing were 4.37 and 3.72% respectively, and for water content 28.9 and 19.32% respectively. Barber (2), reported coefficients of variation between 1.7 and 10% for bulk density and between 5 and 13% for water content, the values obtained in this trial are into this range for bulk density, but not for water content.

For the evaluations carried out

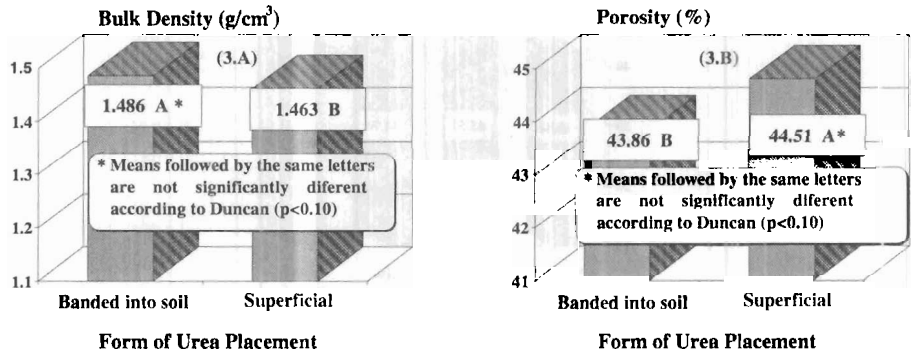


Figure 3. Means for bulk density (g/cm³) (3.A) and porosity (%) (3.B) at 99 days after sowing of a soil fertilized under two forms of urea placement, in the savanna of Jusepín, Monagas State, in rainy season.

Table 2. Means for vacuum relationship 52 days after sowing of a soil cultivated with three sesame varieties (*Sesamum indicum* L.) under four tillage methods in the savanna of Jusepín, Monagas State, in rainy season.

Tillage methods	Vacuum Relationship†		
	Sesame varieties		
	Glauca	Acarigua	Blanca
Chisel	0.933^{Aa}	0.937^{Aa}	0.821^{Bb}
Chisel+Harrow	0.929^{Aa}	0.895^{Aa}	0.855^{Ba}
Minimum Tillage	0.914^{Ab}	0.898^{Ab}	1.019^{Aa}
Harrow	0.960^{Aa}	0.926^{Aa}	0.819^{Bb}

† Duncan's Multiple Range Test at the 10% level of probability
Means followed by the same letters are not significantly different. Uppercase letters for vertical comparisons, lowercase letters for horizontal comparisons.

at 52 days after sowing, the soil physical parameters, bulk density, vacuum relationship and porosity were very similar among the different tillage methods under each variety, but for the evaluations carried out at 99 days after sowing, harrowing had a greater bulk density and a lower vacuum relationship and soil porosity, this suggests that there was not soil compaction due to any tillage method at 52 days but that application of three har-

Table 3. Means for porosity (%) 52 days after sowing of a soil cultivated with three sesame varieties (*Sesamum indicum* L.) under four tillage methods in the savanna of Jusepín, Monagas State, in rainy season.

Tillage methods	Porosity (%)†		
	Sesame varieties		
	Glauca	Acarigua	Blanca
Chisel	48.15^{Aa}	48.08^{Aa}	44.81^{Bb}
Chisel+Harrow	47.84^{Aa}	47.15^{Aa}	45.88^{Ba}
Minimum Tillage	47.69^{Ab}	47.25^{Ab}	50.31^{Aa}
Harrow	48.69^{Aa}	47.90^{Aa}	44.93^{Bb}

† Duncan's Multiple Range Test at the 10 % level of probability.
Means followed by the same letters are not significantly different. Uppercase letters for vertical comparisons, lowercase letters for horizontal comparisons.

row passes caused a slight compaction at 99 days, since according to Pla (16, 17), and Lugo (14), the compaction implies a decrease in volume or increase in bulk density when soils respond to external forces; therefore, the first impact of the compaction is the reduction of the pore volume and of the redistribution in the pore percentage. On the other hand, Pla (15), has expressed that tillage generally tend to diminish, at least temporarily, the bulk density and to increase the total porosity. According to Lugo (14), the bulk density has been broadly used to point out probabilities of root penetration into the soil, but although its increment is a good indicator of compaction, its value is not appropriate to determine compacted layers.

Bulk density varied between 1.317 and 1.463 g/cm^3 at 52 days after sowing (table 1) and between 1.444 and 1.540 at 99 days after sowing (figure 2). According to Gavande (8), it has been determined that roots do not penetrate when bulk density has high values, for soils of coarse texture, the critical limit for root penetration is from 1.6 to 1.7 g/cm^3, while Brady (3), reports that cotton crop roots (with a similar root system to that of sesame) can not penetrate in bulk densities greater than 1.8 g/cm^3. According to this, the values of bulk density obtained in this experiment allow to suggest that the root system of the sesame cultivars could explore easily the depth level of 0-30 cm due to the relatively low values of bulk density, although these values are not into the ideal value of the soil bulk density that according to Casanova (5), is between 1.2 and 1.3 g/cm^3. However, Gupta (10), reports that a soil having bulk density between 1.4-1.6 g/cm^3 is considered to be good for plant growth.

On the other hand, Caraballo (4), indicated that Ultisols' bulk density oscillates between 1.4 until almost 2.0 g/cm3. Albornoz *et al.* (1), reported values from 1.64 to 1.88 g/cm^3 for depths between 0-25 cm and 0-200 cm, respectively, for a typical Ultisol of the oriental region of Venezuela. Brady (3), indicated that bulk density variations into the range of 1.2 and 1.8 g/cm^3 can be found in sandy, sandy loam and loamy sand soils and that they could reach up to 2.0 g/cm^3 and Cheema *et al.* (6) indicated that bulk density for most soils varies from 1.0-1.8 g/cm^3. The values found in this experiment, are lightly inferior to those reported by Caraballo (4) and Albornoz *et al.* (1), but they are into the range mentioned by Brady (3) and Cheema *et al.* (6). This could be due to that bulk density exhibits variability in space as in time due to vertical and lateral variations of the soil properties such as: texture, structure, organic matter and water contents (14).

In general, the tillage treatments did not affect considerably the bulk density, vacuum relationship and porosity of the soil. Similar results have been reported by Hill and Cruse (11), who found that tillage treatments (no tillage, reduced tillage and conventional tillage) did not have a statistically significant effect on bulk density in two sites, and Lindwall *et al.* (12) found that tillage treatments (zero tillage and conventional tillage systems) had little effect on soil bulk density.

Other experiments have pointed out different results. Spilde and Delbert (19) indicated that bulk density values of soil under no tillage and minimum tillage tended to be higher than under conventional tillage in the top 6 inches of soil but were not affected at lower depths of a silty clay soil. Fernandes *et al.* (7), found that tillage systems: conventional spring plowed, chisel plowed and no tillage (direct drilling) using a coulter planter, affected bulk density, total porosity and pore size distribution and they concluded that the magnitude of the effect depended on the soil type and soil depth.

In Venezuela, it has been carried out some tillage method experiments on physical properties of the soils. Similar results to those obtained in this trial were reported by Peña (18), who worked with sunflower crop and he did not find significant differences for bulk density under the three evaluated tillage systems (chisel plow + three harrow passes; three harrow passes and minimum tillage) and for bulk density in the soil depths evaluated from 0 to 50 cm. Gil and Albornoz (9), worked with soybean variety 'Guarapiche' in a savanna soil of Anzoátegui State and they found that bulk density between 0-10 cm was greater in the minimum tillage than in four harrow passes, but not for bulk density between 10-50 cm, the bulk density determinations were carried out each 5 cm.

The inherent discussion to soil vacuum relationship and porosity registers a similar behaviour to that of bulk density, since these two parameters are determined from the bulk density.

In relation to soil water content, it was only found an effect of the cultivars for the evaluation carried out at 52 days after sowing. The data suggest that the variety 'Blanca', consumes less water from the soil than 'Glauca' and 'Acarigua', this could be due to a smaller transpiration of 'Blanca'. Tillage methods did not affect soil water content. Similar results were reported by Lindwall *et al.* (12) who found that tillage treatments (zero tillage and conventional tillage systems) had little effect on soil moisture conservation. Differences between different tillage systems have also been reported for moisture content. Nacci *et al.* (15), pointed out that the conventional tillage (4 harrow passes and a planter pass) tended to maintain a greater humidity in the soil profile than minimum tillage (a pass of rotary cultivator or a pass of rotary cultivator and a planter pass) and the chisel plow (a pass of rotary cultivator, a pass of chisel plow, a harrow pass and a planter pass) and they concluded that this tendency could obey to restrictions in the descending movement of the water, due to the compaction effect caused by tillage, resulting in a higher water content in the superior strata. While López (13), concluded that in the superficial soil layer the moisture was affected by tillage treatments, according to the sowing time and Peña (18), concluded that minimum tillage system has advantages in comparison with chisel plow + three passes of harrow or three passes of harrow and under the treatment of minimum tillage, the highest water

contents stored in the root activity zone were achieved.

The greatest bulk density and the lowest porosity obtained with the urea placement banded into the soil could be due to that it probably caused a desegregation of the particles, on the other hand, with the application banded into the soil, there is a larger traffic of people and they remain more time in the plots, also there is an implement use, all this could contribute for an increment of bulk density and a decrease of porosity in the soil superficial horizon where soil samples were taken.

Conclusions

At 52 days after sowing, the greatest soil water content occurred in plots cultivated with variety 'Blanca'. Bulk density, vacuum relationship and porosity were similar in all tillage methods upon the three cultivars. Plots sowed with cultivar 'Blanca', presented a smaller bulk density, a bigger vacuum relationship and porosity with minimum tillage, plots sowed with 'Glauca' and 'Acarigua" presented a smaller bulk density, a larger vacuum relationship and porosity with chisel and harrow, while in the chisel+harrow method, plots presented similar bulk densities, vacuum relationships and porosities.

At 99 days after sowing, for the form of urea placement, the smallest bulk density and the largest porosity occurred in plots where urea was placed banded on soil surface. In relation to the tillage methods, the smallest bulk density and the largest vacuum relationship and porosity occurred in the chisel, harrow and chisel+harrow treatments.

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Literature cited

1. Albornoz, A., A. González., y O. Fuentes. 1995. Aspectos físicos de las sabanas orientales venezolanas. p. 33-37. En: Taller: Aspectos físicos de los suelos de las sabanas orientales y su efecto sobre la productividad. Compiladores María Sindoni, Luisa Caraballo y Tania Rodríguez. San Tomé, 5 al 8 de abril de 1.994. Maracay, Venezuela, Fonaiap (Publicación especial N° 30).

2. Barber, R. G. 1995. Procedimientos y metodologías para investigaciones sobre labranza. p. 147-178. En: Efecto de los sistemas de labranza en la degradación y productividad de los suelos Conservacionista. Editores Ildefonso Pla Sentís y Francisco Ovalles. Memorias de la segunda Reunión Latinoamericana de Labranza, Maracay, Venezuela, FONAIAP-FAO-ISSS-UNELLEZ-RELACO. (Series especiales No. 32).

3. Brady, N. C. 1974. The nature and properties of soils. Eighth Edition. Mac Millan Publishing Co. Inc. New York, U.S.A.

4. Caraballo de Silva, L. 1995. Propiedades físicas de los suelos de las sabanas orientales. p. 41-42. En: Taller: Aspectos físicos de los suelos de las sabanas orientales y su efecto sobre la productividad. Compiladores María Sindoni, Luisa Caraballo y Tania Rodríguez San Tomé, 5 al 8 de abril de 1.994. Maracay, Venezuela, Fonaiap (Publicación especial N° 30).

5. Casanova O, E. F. 1994. Introducción a la ciencia del suelo. Primera Reimpresión. Universidad Central de Venezuela, Caracas, Venezuela.

6. Cheema, S. S., B. K. Dhaliwal., and T. S. Sahota. 1991. Agronomy: Theory & Digest. First Edition. Kalyani Publishers. Ludhiana. India.

7. Fernandes, B., H. M. Galloway., R. D. Bronmson., e J. V. Mannering. 1983. Efeito de tres sistemas de preparo do solo na densidade aparente, na porosidade total e na distribuicao dos poros, em dois solos (Typic Argiaquoll e Typic Hapludalf). Revista Brasileira de Ciencia do Solo 7 (3): 329-333.

8. Gavande, S. 1972. Física de suelos. Principios y aplicaciones. Editorial Limusa-Wilmy, S. A. México.

9. Gil, L. R., y B. A. Albornoz. 1995. Evaluación de propiedades físicas del suelo en sistemas de labranza mínima en suelos arenosos del Oriente de Venezuela. p. 193-209. En: Efecto de los sistemas de labranza en la degradación y productividad de los suelos Conservacionista. Editores Ildefonso Pla Sentís y Francisco Ovalles. Memorias de la segunda Reunión Latinoamericana de Labranza, Maracay, Venezuela, FONAIAP-FAO-ISSS-UNELLEZ-RELACO. (Serie especiales No. 32).

10. Gupta, A. K. 1994. Soil Science. p. 1-39. In S. S. Singh, P. Gupta and A. K. Gupta (Eds). Handbook of agricultural sciences. Second Revised Edition. Kalyani Publishers. Ludhiana. India.

11. Hill, R. L. and R. M. Cruse. 1985. Tillage effects on bulk density and soil strength of two mollisols. Journal of Soil Science Society of America 49 (5): 1270-1273.

12. Lindwall, C. W., B. Sawatzky, and T. Jensen. 1984. Zero tillage in southern Alberta. Soil and Fertilizer Abstracts 1987-050-00396.

13. López, R. 1995. Influencia de la época, labranza convencional y siembra directa en la densidad aparente, relación de vacío y % de humedad del suelo y en la productividad del frijol en sabana. p. 290-296. En: Memorias del V Congreso Venezolano de Ingeniería Agrícola. Maracaibo, Estado Zulia, septiembre 1995.

14. Lugo, J. 1995. Compactación de suelos bajo uso agrícola. p. 47-49. En: Taller: Aspectos físicos de los suelos de las sabanas orientales y su efecto sobre la productividad. Compiladores María Sindoni, Luisa Caraballo y Tania Rodríguez San Tomé, 5 al 8 de abril de 1.994. Maracay, Venezuela, Fonaiap (Publicación especial N° 30).

15. Nacci, S., E. Cabrera de B y J. V. Salazar. 1991. Efecto del método de labranza sobre las propiedades físicas de los suelos de las mesas orientales de Monagas. p. 164-174. En: Manual de sistemas de labranza para América Latina. Curso de capacitación sobre sistemas de labranza, Argentina. INTA-FAO. Boletín de Suelos de la FAO N° 66.

16. Pla S, I. 1995. Labranza y propiedades físicas de los suelos. Efecto de los sistemas de labranza en la degradación y productividad de los suelos Conservacionista. Editores Ildefonso Pla Sentís y Francisco Ovalles. p. 26-41. En: Memorias de la segunda Reunión Latinoamericana de Labranza, Maracay, Venezuela, FONAIAP-FAO-ISSS-UNELLEZ-RELACO. (Serie especiales No. 32).

17. Pla S, I, 1995. Principales limitaciones físicas de los suelos, sus causas y efectos sobre la productividad. **Traducido por Luisa de Silva y Tania** Rodríguez Salazar. p. 13-17. En: Taller: Aspectos físicos de los suelos de las sabanas orientales y su efecto sobre la productividad. Compiladores María Sindoni, Luisa Caraballo y Tania Rodríguez San Tomé, 5 al 8 de abril de 1.994. Maracay, Venezuela, Fonaiap (Publicación especial N° 30).

18. Peña, J. 1995. Efectos de diferentes sistemas de labranza sobre el comportamiento del cultivo de girasol (Helianthus annuus L.). p 209-217. En: Memorias del V Congreso **Venezolano de Ingeniería Agrícola.** Maracaibo, Estado Zulia, septiembre 1995.

19. Spilde, L. A. and E. J. Delbert. 1986. Crop yield, water use and soil property changes with conventional, minimum, and no-till systems in the Red River valley. North Dakota Farm Research 43 (4): 22-25.