ORIGINAL ARTICLE

Estimation of Water Available for Plants in Cuban Soils as a Function of Prevailing Texture

Estimación del agua disponible para las plantas en suelos cubanos en función de la textura predominante

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ABSTRACT: The objective of this work is to determine the total soil water availability and easily usable reserve for plants as a function of predominant soil texture. That will be done from information existing for the most important Cuban soils. It will be used as a tool that facilitates efficient irrigation programming. Data were available from 131 soil subtypes and 11 soil groupings, according to the database of the Agricultural Engineering Research Institute (IAgric) of Cuba. The soil depth considered was 0.5 m and a predominant particle size value was assigned to each soil profile according to its texture. Values were adjusted with a logarithmic regression analysis of the gravimetric and volumetric soil water content corresponding to the point of field capacity (Cc) and permanent wilting point (PMP). The values of the Total Available Water in the Soil (ADP) and the Easily Usable Reserve (RFU) were also quantified. The obtained relationships allow predicting in more than 90%, the variation of the limits of these soil water reserves, based on the predominant particle size in its textural composition. The ranges of variation of these limits are higher than the ranges defined at international level for silt and clay, which is associated with the characteristics of the predominant clay in many Cuban soils. The results have a high practical value as a basis for the efficient programming of crop irrigation and allow reducing the hard field and laboratory work involved in these studies.

Keywords: soil textural composition, soil available water limits, easily usable soil water reserve.

RESUMEN: El objetivo del presente trabajo es determinar a partir de la información disponible para los suelos de mayor importancia agrícola de Cuba, la disponibilidad total del agua y la reserva fácilmente utilizable para las plantas en función de la textura predominante, como herramienta que facilite la programación eficiente del riego. Se dispuso de datos de 131 subtipos y 11 agrupamientos de suelos, según la base de datos del Instituto de Investigaciones de Ingeniería Agrícola (IAgric) de Cuba. La profundidad considerada fue de 0,5 m y se asignó a cada perfil de suelo un valor de tamaño de partícula predominante según su textura. Se ajustaron los valores con un análisis de regresión logarítmica de las humedades gravimétricas y volumétricas correspondientes al punto de capacidad de campo (Cc) y punto de marchitez permanente (PMP). Se cuantificaron los valores del Agua total Disponible en el suelo (ADP) y la Reserva Fácilmente Utilizable (RFU) para las plantas. Las relaciones obtenidas permiten predecir en más del 90%, la variación de los límites de estas reservas en función del tamaño de partícula predominante en la textura del suelo. Los rangos de variación de estos límites son superiores a los definidos a nivel internacional para las clases texturales de limo y arcilla, lo que se asocia a las características de la arcilla predominante en muchos suelos cubanos. Los resultados tienen un alto valor práctico para la programación eficiente del riego de los cultivos y permiten disminuir el engorroso trabajo de campo y laboratorio implicado en estos estudios.

Palabras clave: composición textural, límites del agua disponible, reserva fácilmente utilizable.

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INTRODUCTION

Soils can store different amounts of water depending mainly on their basic physical properties, like texture, structure and the content of organic matter, which influences in a particular way. The total amount of water available in the soil for plants (ADP) is the difference between the stored water at the maximum retention or storage limit known as "Field Capacity" (Cc) and the minimum storage limit, known as "Permanent Wilting Point" (PMP). Both are considered up to the depth of interest for plants or effective root depth (Zr), (Gardner, 1988; Hillel, 1998; Reichardt y Timm, 2004; U.S. Department of Agriculture, 2005; Allen *et al.*, 2006).

A fraction of water depletion from field capacity to a point defined primarily by the characteristics of the crop, among other factors, represents the "water or reserve readily or easily available for plants" (RFU). The adequate selection of this point implies the definition of the ideal operating criterion for irrigation planning (Allen *et al.*, 2006).

The first works carried out in Cuba on water available for plants in Cuban soils date back to the 1960s and were based on the morphological classification of soils valid in Cuba at that time. Only destructive methods of sample processing and different concepts of water retention energy in the soil were used. In this sense, the works of Nakaidze and Simeón (1972), Simeon (1979), Klimes *et al.* (1980) and others were important.

Later, in the decade of 1980, associated to the works for the elaboration of the map of Cuban soils, at scale 1:25 000 and to the generalized application of the irrigation forecast (Rey *et al.* ,1982), deeper studies were done about water availability for plants in different Cuban soils by different scientific and technical entities. The former Irrigation and Drainage Research Institute (IIRD), today, Agricultural Engineering Research Institute (IAgric), led them. These studies were made based on the current genetic classification of Cuban soils.

The continuity and updating of these studies have been carried out to date from different works of Master's and Doctorate's thesis and national and international research projects. They have also been performed from scientific and technical services provided by researchers and specialists of IAgric to different national entities. That has generated a database with information on the physical properties of the main soil types in the country, taking into account, also, correlations with the latest Genetic Classification of Cuban soils (Cid *et al.*, 2011).

The objective of this work is to determine the availability of total water and the reserve easily usable for plants, based on the predominant texture, as a tool that facilitates efficient irrigation programming based on the information available for the most important agricultural soils in Cuba.

METHODS

Database

For the research, the database of Agricultural Engineering Research Institute (IAgric) belonging to the Ministry of Agriculture of Cuba was available. Data were obtained from 131 subtypes of soils corresponding to 11 soil groupings, according to the last classification of soils valid in Cuba (Hernández *et al.*, 2015).

The studied soils belong to the groupings: Alitic, Ferritic, Ferralitic, Fersialitic, Sialitic Brown, Sialic Humic, Vertisol, Hydromorphic, Halomorphic, Fluvisol and Histosol. Only the soils belonging to the Ferralics, Histosols, Poor Evolved and Androsols groupings of this last mentioned classification were missing.

The physical properties of the soils considered and the methods used for their determination appear in Table 1.

TABLE 1. Physical and hydrophysical properties studied and methods used

Properties	Determination Method
Texture	Method of the Pipette
Field Capacity	Plazoleta Method
Permanent Wilting Point	Method of the Membrane (tension 15 atm.)
Bulk Density	Ring method (undisturbed samples)
Soil water content	Gravimetric Method

Data Processing

The layer selected to carry out the studies of each soil profile was from 0 to 0.5 m, taking into account the depth reached by the roots of most of the economic important crops under irrigation in Cuba (Chaterlán *et al.*, 2010; Zamora *et al.*, 2014).

The data of each evaluated soil profile were organized, assigning to it a predominant particle size value and considering the established ranges for the textural classification in the Interpretation Manual of Cuban Soils (MINAG, 1984).

The intermediate values were adjusted according to a logarithmic regression analysis between the values of gravimetric moisture content corresponding to the point of field capacity (Cc) and permanent wilting point (PMP), and the predominant particle size. A similar logarithmic regression analysis was also performed for the corresponding volumetric moisture content values, calculated according to the expression (Cid *et al.*, 2011):

$$Wv = Wg \cdot Da \quad (1)$$

Where:

Wv - volumetric moisture content ($cm3 \cdot cm^{-3}$)

Wg - gravimetric moisture content ($g \cdot g^{-1}$)

Da - bulk density ($g \cdot cm^{-3}$)

The quality of the regressions was analyzed from the statistic Coefficient of Determination, R^2.

The water depth corresponding to the upper (LSAD) and lower limits (LIAD) of the total available water in the soil for the plant (ADP) were also calculated according to Allen *et al.* (2006). The mean values of volumetric moisture content at field capacity Wv_{Cc} and the permanent wilting point Wv_{PMP}, expressed in% of volume to the root depth of Zr = 0.5 m, were considered as follows:

$$LSAD = Wv_{Cc} \cdot Zr \text{ (mm)} \quad (2)$$

$$LIAD = Wv_{PMP} \cdot Zr \text{ (mm)} \quad (3)$$

Finally, the values of the Total Available Water in the Soil for the Plant (ADP) and the Easily Usable Reserve (RFU) were quantified for each profile. For the calculation of the RFU, the results of previous studies were taken into account. Those define that the maximum yields under irrigation are obtained for the treatments where soil moisture is maintained around 85% of the field capacity corresponding to 50% of the total soil water available for plants (Chaterlán *et al.*, 2010; Zamora *et al.*, 2014).

The calculations were performed as defined by Allen *et al.* (2006), from the following expressions:

$$ADS = LSAD - LIAD \text{ (mm)} \quad (4)$$

$$RFU = 0{,}5 \cdot ADS \text{ (mm)} \quad (5)$$

RESULTS AND DISCUSSION

Figure 1 (A and B) shows the result of the regression analysis carried out between the values of the gravimetric and volumetric soil water content at field capacity, Cc, and permanent wilting point, PMP, and the soil predominant particle sizes.

Logarithmic equations with high values of the coefficient of determination, R^2, were obtained in all cases. That makes possible to affirm that the equations defined for each case, can explain more than 95% of the variations in the gravimetric soil water content as a function of the variations of soil textures and more than 80% of the variations for the case of volumetric soil water content. The decrease of the accuracy of the regressions with the volumetric soil water content can be associated to the variability of the values of bulk density, which is not only associated to the textural changes, but to structural changes that can occur in the same type of soil (Cid *et al.*, 2011; López *et al.*, 2016).

It is recommended, for the practical use of these equations, to use those obtained for gravimetric soil water content and then convert the values to volumetric soil water content using the specific density data for each site.

Other authors have also pointed to the possible relationships that can be established between the variation of the size of the predominant particles in the soils that characterize their texture and the soil water content corresponding to different values of tension or hydraulic conductivity (Zotarelli et al., 2013). These relationships have been called pedotransference equations. The functions developed for European soils by Wösten *et al.* (1998), Jarvis *et al.* (2002) and Zotarelli *et al.* (2013) can be cited as examples.

In Cuba, Ruiz *et al.* (2006), define the pedotransference functions among the methods used to determine the hydraulic properties of

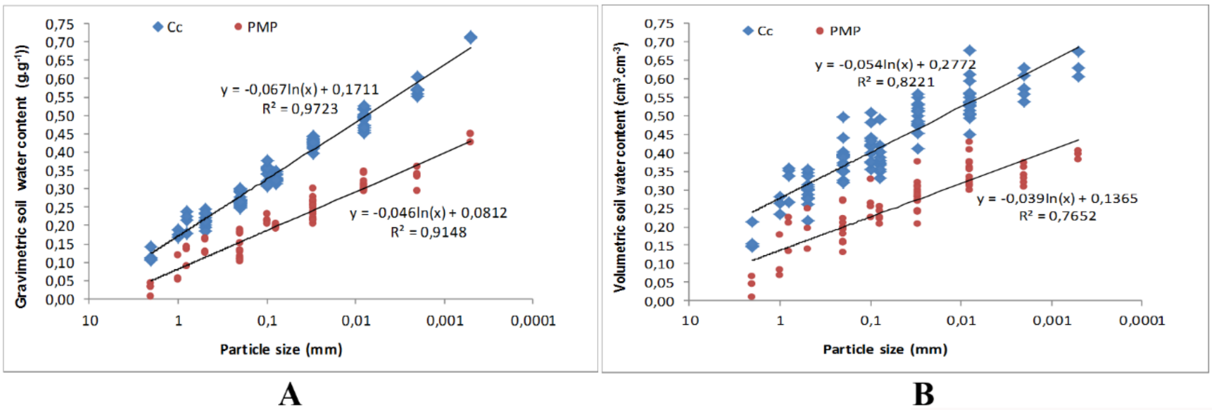


FIGURE 1. Regression curves between the soil moisture values at field capacity, Cc, and permanent wilting point, PMP, and the soil predominant particle sizes: A- for the gravimetric soil water content; B- for volumetric soil water content.

soils. In particular, Medina *et al.* (2002) defined pedotransference functions to estimate the values of the water- tension curve from basic soil physical properties, but only for one type of soil (Ferrallitic).

The fundamental contribution of this work to these antecedent studies is that it involves a wide range of soil types. Besides, it allows the direct estimation of the soil water contents from a single basic soil physical property (the predominant particle size). That define the limits of the total soil water reserve available for the plants, which is essential for irrigation scheduling.

The parameters of the logarithmic equations found were used to represent the tendency of the variation in the soil water content and the water depth corresponding to the parameters that define the soil water availability for the plants, depending on the variation of the soil textural classes (Figure 2).

In this case, the different textural classes, that could be obtained from a laboratory textural analysis, have been represented, as defined in the Cuban Soil Interpretation Manual (MINAG, 1984).

These figures are useful to have a quick approximation to the values that can be expected from the soil water availability for the plants according to the soil textural classification.

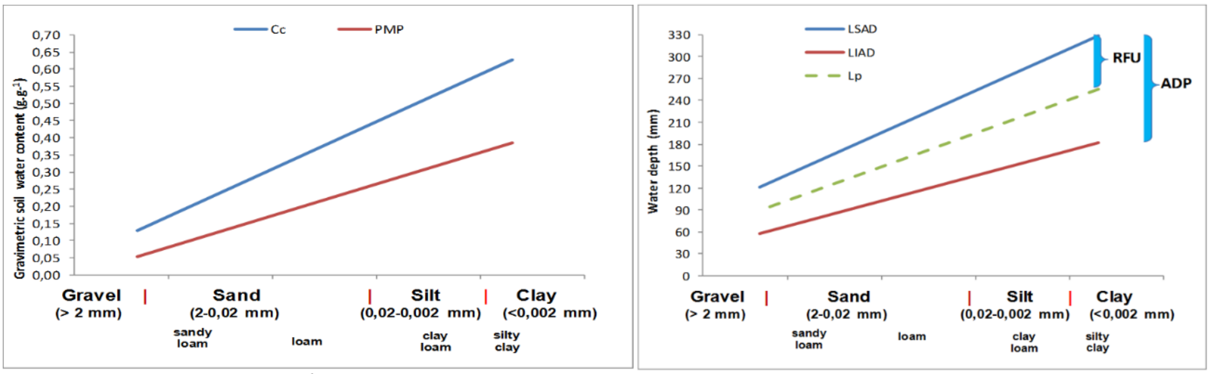
A comparison of these results with the classical scheme presented by Hillel (1998), for these relationships (see Figure 3) allows us to define that the ranges of variation of soil moisture at Cc and PMP estimated for Cuban soils are higher, fundamentally for the textural classes corresponding to silt and clay. This may be associated with the characteristics of the predominant clay in many soils of Cuba that present considerable amounts of smectite and vermiculite, which causes them to tend to expand and contract according to the level of present soil moisture (Cid *et al.*, 2004).

The results summarized in Figure 2 have an important practical value. They are a simple tool that can be used by technicians and producers to define the irrigation schedule of crops, especially, the definition of when and how much to irrigate. That would be derived from the knowledge of the predominant texture in the soil to the depth of 0.5 m, which can be defined from previous soil studies or with a specific textural analysis for the site under study.

However, for the extension of these results application in productive practice, it is necessary a strengthening of the soil textural analysis, that is carried out in different laboratories of the country, by different entities, so that the predominant particle size can be more accurately specified. In this sense, it is recommended to use a weighted average of the particle size, taking into account the percentage of particles present in each textural fraction.

Recommendations for its Practical Implementation

- Take advantage of the potential that is available from international projects and national programs to strengthen the textural analysis of soil laboratories and other entities of the agriculture system.



A B

FIGURE 2. Variation trend of parametres that define soil water availability for plants as a soil texture: A- for gravimetric soil moisture; B- for water depth.

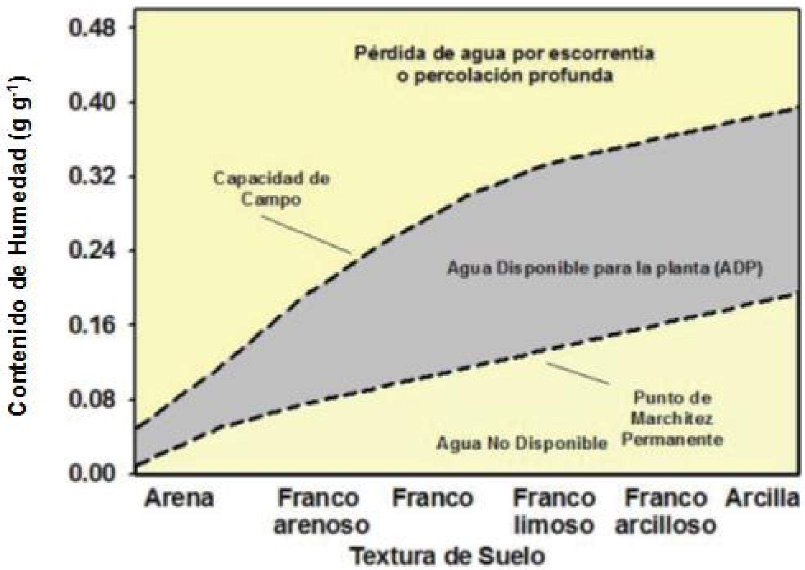


FIGURE 3. General relationship between the soil water available for the plant and present soil texture, by Hillel (1998).

- Train technical personnel directly related to soil and irrigation activity in the production base for the practical use of these relationships.
- Use the relationships obtained as part of the tools included in the Irrigation Advisory Services and, in particular, for irrigation forecasting.
- Perform field validations of these relationships, based on monitoring soil water content in control fields, using current easy-to-use techniques such as electromagnetic probes (TDR).

CONCLUSIONS

- The relationships determined for the most important agricultural soils of Cuba, make it possible to predict, with an accuracy of more than 95%, the variation of the limits of the total soil water reserves and easily usable reserves for the plants based on the predominant particle size in their textural composition.
- The ranges of variation of soil moisture to field capacity, Cc and permanent wilting point, PMP, estimated for Cuban soils, are higher than the ranges defined by international studies, fundamentally for the textural classes corresponding to silt and clay, which is associated with the characteristics of the predominant clay in many Cuban soils.
- The results obtained have a high practical value as a basis for the efficient irrigation programming of crops and allow reducing the

hard field and laboratory work involved in these studies, as well as to promote more precise planning of water resources available for irrigation.

REFERENCES

ALLEN, R.G.; PEREIRA, L.; RAES, D.; SMITH, M.: *Evapotranspiración del cultivo: guías para la determinación de los requerimientos de agua de los cultivos*, Ed. Food & Agriculture Org., @FAO ed., vol. 56, 2006, ISBN: 92-5-304219-2.

CHATERLÁN, D.Y.; DUARTE, D.C.; LÓPEZ, S.T.; PAREDES, P.; PEREIRAS, L.S.: "Determining of crop coefficients for horticultural crops in Cuba through field experiments and water balance simulation", *Revista Ciencias Técnicas Agropecuarias*, 19(1): 90-95, 2010, ISSN: 1010-2760, E-ISSN: 2071-0054.

CID, G.; LÓPEZ, T.; GONZÁLEZ, F.; HERRERA, J.; ELENA RUIZ, M.: "Propiedades físicas de algunos suelos de Cuba y su uso en modelos de simulación", *Revista Ciencias Técnicas Agropecuarias* , 20(2): 42-46, 2011, ISSN: 1010-2760, E-ISSN: 2071-0054.

CID, L.G.; HERRERA, P.J.; SIERRA, O.L.; LÓPEZ, S.T.: "Gestión del agua en el manejo integral de los vertisuelos bajo diferentes agroecosistemas", *Revista Ciencias Técnicas Agropecuarias* , 13(3): 1-5, 2004, ISSN: 1010-2760, E-ISSN: 2071-0054.

GARDNER, E.A.: *Understanding Soils and Soil Data*, Soil Conservation Research Branch ed., vol. Chapter 10, Soil Water, Queensland, 153-184 p., 1988.

HERNÁNDEZ, J.A.; PÉREZ, J.J.M.; BOSCH, I.D.; CASTRO, S.N.: *Clasificación de los suelos de Cuba*, Ed. Ediciones INCA, San José de las Lajas, Mayabeque, Cuba, 2015, ISBN: 978-959-7023-77-7.

HILLEL, D.: *Enviromental Soil Physics*, Ed. Academic Press, USA, 346 p., 1998.

JARVIS, N.J.; ZAVATTARO, L.; RAJKAI, K.; REYNOLDS, W.D.; OLSEN, P.-A.; MCGECHAN, M.; MECKE, M.; MOHANTY, B.; LEEDS, H.P.B.; JACQUES, D.: "Indirect estimation of near-saturated hydraulic conductivity from readily available soil information", *Geoderma*, 108(1-2): 1-17, 2002.

KLIMES, A.S.; SUÁREZ, O.; MESA, A.; PENA, J.: *Suelos de Cuba*, Ed. Orbe, Tomo II. Física del suelo ed., La Habana, Cuba, 328 p., 1980.

LÓPEZ, S.T.; RUÍZ, P.M.E.; GONZÁLEZ, R.F.; CID, L.G..; HERRERA, P.J.: "Actualización de herramientas disponibles para la precisión de balances hídricos del suelo en trabajos experimentales", *Revista Ingeniería Agrícola*, 6(3): 18-25, 2016, ISSN: 2306-1545, E-ISSN: 2227-8761.

MEDINA, H.; TARAWALLY, M.; DEL VALLE, A.; RUIZ, M.E.: "Estimating soil water retention curve in rhodic ferralsols from basic soil data", *Geoderma*, 108(3-4): 277-285, 2002, ISSN: 0016-7061.

MINAG: *Manual de Interpretación de los Suelos cubanos*, ser. Ed. Científico-Técnica, Inst. Ministerio de la Agricultura (MINAG), La Habana, Cuba, 133 p., 1984.

NAKAIDZE, E.K.; SIMEÓN, F.R.: "Características generales de las propiedades hidrofísicas de los principales suelos de Cuba", *Voluntad Hidráulica*, (23): 33-40, 1972, ISSN: 0505-9461, E-1999-2750.

REICHARDT, K.; TIMM, L.C.: *Solo, planta e atmosfera: conceitos, processos e aplicações*, Ed. Manole Ltda., Barueri, SP, Brasil, 478 p., 2004, ISBN: 85-204-1773-6.

REY, R.; HERRERA, J.; ROQUE, R.; LAMELA, C.: "El pronostico de riego en Cuba.", *Ciencia y Tecnica en la Agricultura. Riego y Drenaje*, 5(1): 10-15, 1982, ISSN: 0138-8487.

RUIZ, P.M.E.; MEDINA, H.; HERRERA, P.J.: "Métodos empleados en Cuba para determinar las propiedades hidráulicas de suelos", *Terra Latinoamericana*, 24(3): 311-318, 2006, ISSN: 0187-5779.

SIMEON, F.R.: "Características de las propiedades hidrofísicas de los principales suelos agrícolas de Cuba", *Voluntad hidráulica*, 16(49-50): 16-23, 1979, ISSN: 0505-9461, E-1999-2750.

U.S. DEPARTMENT OF AGRICULTURE: *Natural Resources Conservation Service. National Soil Survey Handbook, title 430-VI. Soil Properties and Qualities (Part 618), Available Water Capacity (618.05) [en línea]* 2005, USA, *Disponible en:*Disponible en:http://soils.usda.gov/technical/handbook , *[Consulta: 17 de diciembre de 2017*].

WÖSTEN, J.H.M.; LILLY, A.; NEMES, A.; LE BAS, C.: *Using existing soil data to derive hydraulic parameters for simulation models in environmental studies and in land use planning*, Ed. Report, WinandStaring Centre, SC-DLO, Wageningen ed., vol. 156, Netherlands, 106 p., 1998.

ZAMORA, H.E.; CARMEN, D.C.; CUN, R.; PÉREZ, R.; LEÓN, M.: "Coeficientes de cultivos (Kc) en Cuba", *Revista Ingeniería Agrícola* , 4(3): 16-22, 2014, ISSN: 2306-1545, E-ISSN: 2227-8761.

ZOTARELLI, L.D.; DUKES, Y.; MORGAN, T.: *Interpretación del Contenido de la Humedad del Suelo para Determinar Capacidad de Campo y Evitar Riego Excesivo en Suelos Arenosos Utilizando Sensores de Humedad*, *[en línea]*, Inst. Universidad de Florida, Instituto de Alimentos y Ciencias Agrícolas, Departamento de Ingeniería Agrícola y Biológica, Servicio de Extensión Cooperativa, USA, 2013, *Disponible en:*Disponible en:http://edis.ifas.ufl.edu , *[Consulta: 17 de diciembre de 2017*].

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