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Sprinkler irrigation and soil tillage practices in sugarcane plantations as influenced by soil texture and water storage in northern Ivory Coast

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ABSTRACT

Objective: Soil survey investigations were carried out in Ferké 1 as well as Ferké 2 sugar mills of northern Ivory Coast to determine soil texture and water storage capacity for sprinkler irrigation and tillage management. The sugarcane farmlands being investigated since 2008 in both locations reached 95 % of the total area under cultivation (11,400 ha).
Methodology and results: Soil sampling was achieved after harvest or prior to re-plantation in 5 different spots along 2 transects over 30 cm depth, in every farmland as to get an average soil sample of 1.5-2 kg. Soil physical properties like texture and water retention curves were determined locally in the sugar company's soil laboratory. The results showed that majority of farmland soils investigated was coarse-textured for about 64 % in Ferké 1 and 85 % in Ferké 2, with a lower to medium water storage capacity (70-89 mm) over 60 cm depth which corresponds to a readily available moisture less than 60 mm. These light soils were much suitable for the practice of minimum tillage which importantly contributes to reduce sugarcane production costs. The other textural categories such as sandy-clay or clay-loam, rather well balanced and less suitable for the practice of reduced tillage without pre-watering, gave medium to high total available moisture (90-110 mm) and therefore a maximum irrigation application rate (or readily available moisture) of 60-70 mm. Except for the sugarcane plant crop, no significant difference in cane yields resulting from tillage practices was observed over four consecutive cropping seasons. The yield decline from plant cane to first ratoon is very high under conventional tillage (-16 t/ha) compared with the reduced tillage (+3 t/ha). Even higher cane yield was obtained on the second ratoon (89 t/ha) compared with the conventional tillage (83 t/ha).
Conclusion and application: Better knowledge of soil texture as well as total available moisture resulted in improved practices of sprinkler irrigation and soil tillage in Ivorian sugarcane plantations.
Key word: particle size distribution, physical property, water retention, available moisture, reduced tillage, irrigation management

RÉSUMÉ

Influence de la texture et du stock hydrique du sol sur l'irrigation par aspersion et le travail du sol dans les plantations de canne à sucre au Nord de la Côte d'Ivoire
Objectifs : Des prospections pédologiques ont été conduites dans les périmètres sucriers de Ferké 1 et Ferké 2 au Nord de la Côte d'Ivoire afin de déterminer la texture et la réserve en eau utile des sols pour la gestion de l'irrigation par aspersion et du travail du sol.

Méthodologie et résultats : Les parcelles prospectées depuis 2008 dans les deux périmètres représentent 95 % de la superficie totale sous culture, soit 11400 ha. L'échantillonnage du sol, par parcelle de 30 à 40 ha avec des lignes de canne longues de 432 m, a été effectué après la récolte ou avant la replantation en 5 points, suivant 2 transects médians, sur une profondeur de 30 cm afin d'obtenir un échantillon moyen de 1.5 à 2 kg. Les propriétés physiques du sol telles que la texture et les courbes de rétention en eau ont été déterminées sur place au laboratoire de la compagnie sucrière. Il en résulte que la majorité des sols prospectés est sablonneuse, soit 64 % du parcellaire à Ferké 1 et 85 % à Ferké 2, avec une réserve en eau utile faible à moyenne (70-89 mm) sur 60 cm de profondeur et une réserve facilement utilisable inférieure à 60 mm. Ces sols légers sont adaptés au travail minimum du sol qui contribue de façon importante à la réduction des coûts de production. Les autres classes texturales telles que sablo-argileuse ou argilo-limoneuse, plus équilibrées et moins adaptées au travail minimum du sol sans pré-irrigation, ont une réserve en eau utile moyenne à forte (90-110 mm) soit une RFU de 60-70 mm. De plus, à l'exception de la canne vierge, les différences de rendements constatées entre le labour classique et le labour minimum n'étaient pas significatives. De la vierge à la 1ère repousse, une perte importante de rendement en canne a été enregistrée en labour classique (-16 t/ha) contre un gain de 3 t/ha avec le travail minimum du sol. Un rendement plus élevé a même été obtenu en 2ème repousse avec le travail minimum du sol, soit 89 t/ha contre 83 t/ha pour le labour classique.

Conclusion et application : La bonne connaissance de la texture et de la réserve utile en eau des sols a permis d'améliorer significativement la pratique de l'irrigation par aspersion et du travail du sol dans les plantations de canne à sucre au Nord Côte d'Ivoire.

Mots clés : analyse texturale, propriété physique, rétention hydrique, réserve hydrique, travail minimum, gestion de l'irrigation.

INTRODUCTION

The Ivorian sugarcane industry has been facing a lack of competitiveness for two decades, due to yield decline and high production costs. The yield decline has to be related to soil fertility decline as a result of a very low soil organic matter content (0.4 -2.0 %) and poor management practices regarding irrigation, soil tillage, cane harvesting and long-term monoculture of sugarcane (Péné and Koulibaly, 2001). In particular, soil organic matter is impeded by burn-cane harvesting as well as excessive tillage without pre-irrigation in order to remove soil compaction due to heavy machinery with indiscriminate traffic especially at harvest.

Soil texture has a very important influence on the flow of soil water, the circulation of air, and the rate of chemical transformations which are of importance to plant life. The size of soil particles has a great influence on crop production the world over, but to the irrigation farmer it is particularly important because it determines in a large measure the depth of water he can store in a given depth of soil (Péné et al., 2012). The existence of granules assures a desirable soil structure. Excessive irrigation, ploughing, or otherwise working fine-textured soils, when either too wet or too dry, tends to break down these granules. Favourable structure in fine-textured soils is essential to the satisfactory movement of water and air. Favourable soil structure is recognized as the key to soil fertility. Adequate amounts of chemical nutrients in soils, though essential to crop production, do not assure satisfactory plant growth and crop yields. The permeability of soils to water, air, and roots, provided by favourable soil structure, is equally important to crop growth as are adequate supplies of nutrients. The primary function of organic matter as well as humus is to add stability to soil aggregates, serving as a cushion against the shock of tillage (Williams and Petticrew, 2009).

The practice of sprinkler irrigation in Ferké sugarcane farm without enough knowledge of soil texture and water content-matric potential relations resulted in poor estimates of available soil moisture and therefore inappropriate application rates of irrigation associated with a lower crop water use with such consequences as nutrient leaching below the root zone, soil erosion and high production costs. Yield decline in sugarcane, defined as the loss of productive capacity of soils under long-term monoculture used to be a widespread problem throughout the Australian sugar industry (Garside *et al*., 1997a). It is believed to be caused by a combination of factors associated with current sugarcane management system, including the growth of sugarcane as a monoculture, the frequent aggressive tillage of the soil between crop cycles and the use of heavy harvesting machinery. These practices have resulted in sugarcane soils becoming physically, chemically and biologically degraded and as a consequence the development of different soil organisms detrimental to the growth of sugarcane (Garside *et al*., 1997b; Stirling *et al*., 1999; Pankhurst *et al*., 2003). The introduction of rotation breaks, notably an alternate crop such as soybean or a sown pasture has been shown to be effective in improving sugarcane yields (Garside *et al*., 1999) and soil health generally. A major factor associated with the yield responses following different rotations breaks was rotation-induced changes in the composition of the soil biota. The changes included a reduction in the populations of root pathogens known to be associated with yield decline (i.e. the rot fungus *Pachymetra chaunorhiza*, and the lesion nematode *Pratylenchus zeae* (Stirling *et al*., 2001). The objective of the study was to determine soil texture, water content-matric potential relations and the available soil moisture for sprinkler irrigation as well as tillage management purposes.

MATERIAL AND METHODS

Ferké sugarcane farmlands: The survey was carried out on Ferké 1 and Ferké 2 sugarcane plantations in northern Ivory Coast respectively 8 and 45 m away from the city of Ferké (09°35'N, 05°12W, 330 m ASL). The prevailing climate is tropical dry with a one-modal rainfall pattern averaging 1200 mm/year. The 7-month rainy season takes place from April to October, August and September being highly wetted with a total rainfall of 500-600 mm. The 5-month dry season starting from November to March, is marked by a hot as well as dry wind originating from the Sahara, namely the *harmattan* which prevails from November to January with the highest magnitude of daily temperatures (+10-20 °C). The vegetation is Guinea savannah with some thin rain forests along waterways. Soils are mainly ferralsols and occasionally alluvial soils or hydromorphic soils in valley bottoms as well as in uplands where water infiltration is limited by impermeable layers. Both Ferké sugar mills cover a total farmland of 12,000 ha which are mainly under sprinkler as well as drip irrigation. In addition, about 2,000 ha are devoted to rain-fed sugarcane village plantations.

Soil sampling: Soil sampling was achieved after harvest for a ratoon crop or prior to re-plantation for a plant crop. This was made at 5 different spots along 2 transects over 30 cm depth in every farmland, to be analysed chemically. Every farmland covers about 30-40 ha with 432 m-long cane rows as to get an average soil sample of 1.5-2 kg for laboratory investigations.

Soil texture analysis: Soil samples were air-dried, ground and sieved through a 2 mm mesh. Particle size distribution was determined using the Robinson's pipette method after the sample is cleaned from organic matter with oxygen water and dispersed by rotational shaking in presence of sodium hexa-meta-phosphate (1 g/l). Soil sample suspension is then sieved through 200 µm as well as 50 µm meshes for collecting coarse-sand (2000 – 200 µm) and fine sand (200 – 50 µm) respectively which are heavily washed with distilled water, oven-dried over 24 h at 105 °C and weighed. The excess washing water is added to the 50-0 µm suspension which is transferred to a 1000 ml-measuring cylinder where hydrometer readings are taken after regular intervals in order to collect clay (2 – 0 µm) and fine silt (20 – 2 µm) and coarse-silt (50 – 20 µm). Sedimentation time and hydrometer readings at a given temperature are used to determine the grain size according to the Stokes' law (Naime *et al*, 2001; Teepe *et al*, 2003). All different particle fractions collected are oven-dried over 24 h at 105 °C, weighed and expressed in %.

Measurement of soil water retention: The relevant equipment is a set of ceramic plates placed in an extractor which is operated by a compressor. Soil moisture is removed from soil samples by raising air pressure in an extractor. A porous ceramic plate serves as a hydraulic link for water to move from the soil to the exterior of the extractor. The smaller the soil pore size, the higher pressure can be before air will pass through. The drawing of the moisture retention curve regarding a soil requires putting the moist soil sample at different known pF values (2.5, 3.0, 3.5, 4.2) till equilibrium and each time determining the volumetric soil water content. Equilibrium is reached when water flow from the outflow tube ceases. At equilibrium, there is an exact relationship between the air pressure in the extractor and the soil suction (and hence the moisture content) in the samples. The difference in moisture content of the soil between field capacity (pF=2.5) and permanent wilting point (pF=4.2) is termed the available moisture or total available moisture (TAM). The readily available moisture (RAM) is the portion (2/3) of the available moisture that is most easily extracted by plants.

They are expressed as follows:

$TAM = (\Theta v_{pF2.5} - \Theta v_{pF4.2}) . z$

Where:

$\Theta v_{pF2.5}$ = volumetric water content at pF 2.5 (field capacity)

$\Theta v_{pF4.2}$ = volumetric water content at pF 4.2 (permanent wilting point)

Z: crop rooting depth.

$\Theta v = \Theta g. D_{bulk}$

Θg: gravimetric water content and D_{bulk} the soil bulk density

Field capacity is defined as the soil moisture content when the gravitational water has been removed. The soil moisture content when plants permanently wilt is called the permanent wilting point or the wilting coefficient.

Irrigation systems practiced: Irrigation water is provided by electrical pumping from Bandama and Lokpoho river-reservoirs whose storage capacities are respectively 70 and 10 million m^3 of water. Sprinkler irrigation systems, namely center-pivot, lateral move, travelling big gun and covering classical sprayer, are practiced over 10,600 h) compared with drip irrigation over 500 ha (5 %). In both sugar mills, center-pivot and classical sprinkler irrigation systems are mostly operated for a total irrigated farmland of 8,000 ha (80 %).

Reduced soil tillage: The reduced soil tillage involves the killing of some early stage cane ratoons with herbicide (Glyphosate) and pre-watering before the step of simultaneous soil de-compaction and double disc opening of the previous cane crop inter-rows. Therefore, tillage operations being eliminated in the technique compared with the traditional one concern the use of disc plough as well as disc harrow. Much more recommended reduced tillage requires traffic control of heavy machinery especially at harvest, breaking of cane monoculture with a legume crop like soybean, groundnut or lablab for up-grading soil health and replanting in the previous cane rows instead of inter-rows for better crop use of soil organic matter. An observation experiment was carried out over a 28 ha-commercial farm with 2 tillage treatments in 3 replicates each. The total area covered by each treatment was 14 ha. Replicates of both treatments were set up alternately for minimizing experimental error. The sugarcane crop (FR8069 variety) was planted early February 2007 in simple rows of 432 m-long. The experiment was conducted under sprinkler irrigation over 4 consecutive years as plant crop followed by 3 ratoons.

RESULTS AND DISCUSSION

Soil texture and water storage capacity: The majority of the farmland soils investigated was coarse-textured for about 64 % in Ferké 1 and 85 % in Ferké 2, with a lower to medium water storage capacity (70-89 mm) over 60 cm depth which corresponds to a readily available moisture less than 60 mm (fig. 1 and 2). These light soils were much suitable for the practice of minimum tillage which importantly contributes to reduced sugarcane production costs. The other textural categories such as sandy-clay or clay-loam, rather well balanced and less suitable for the practice of reduced tillage without pre-watering, gave medium to high total available moisture (90-110 mm) and therefore a maximum irrigation application rate (or readily available moisture) of 60-70 mm

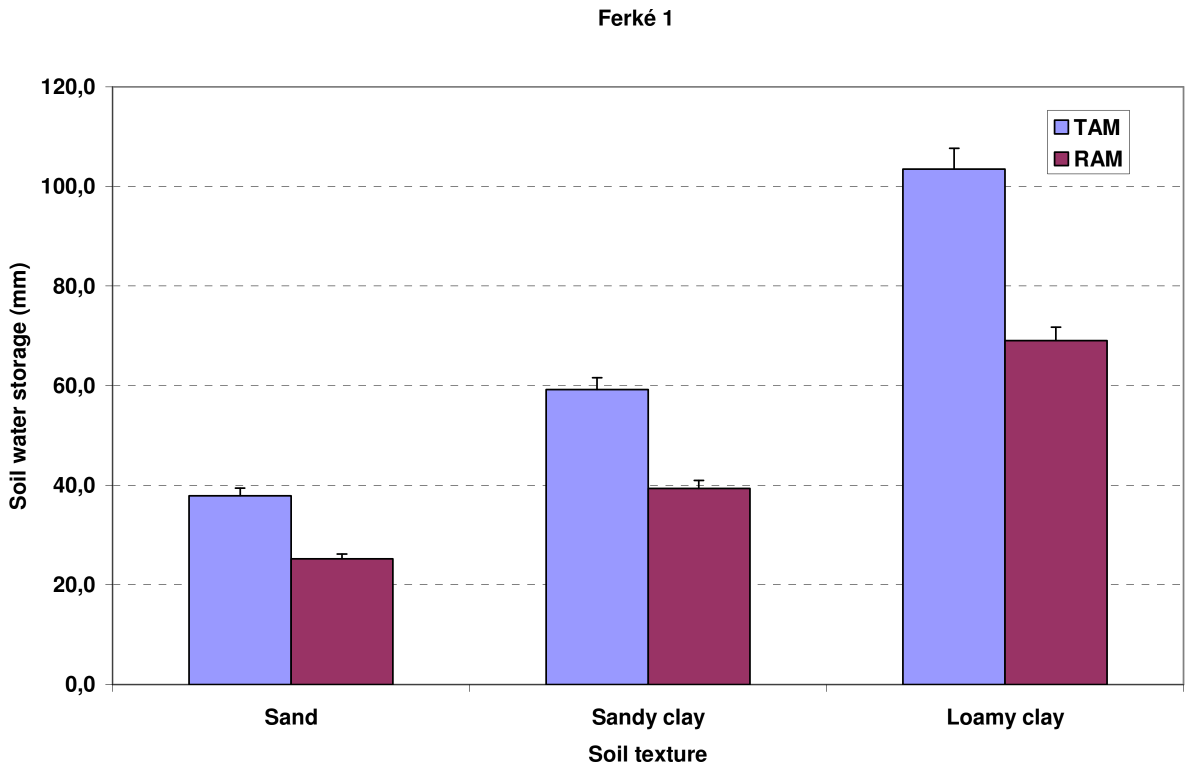

Figure 1: Total and readily available moisture for 3 different soil types in Ferké 1 sugar mill.

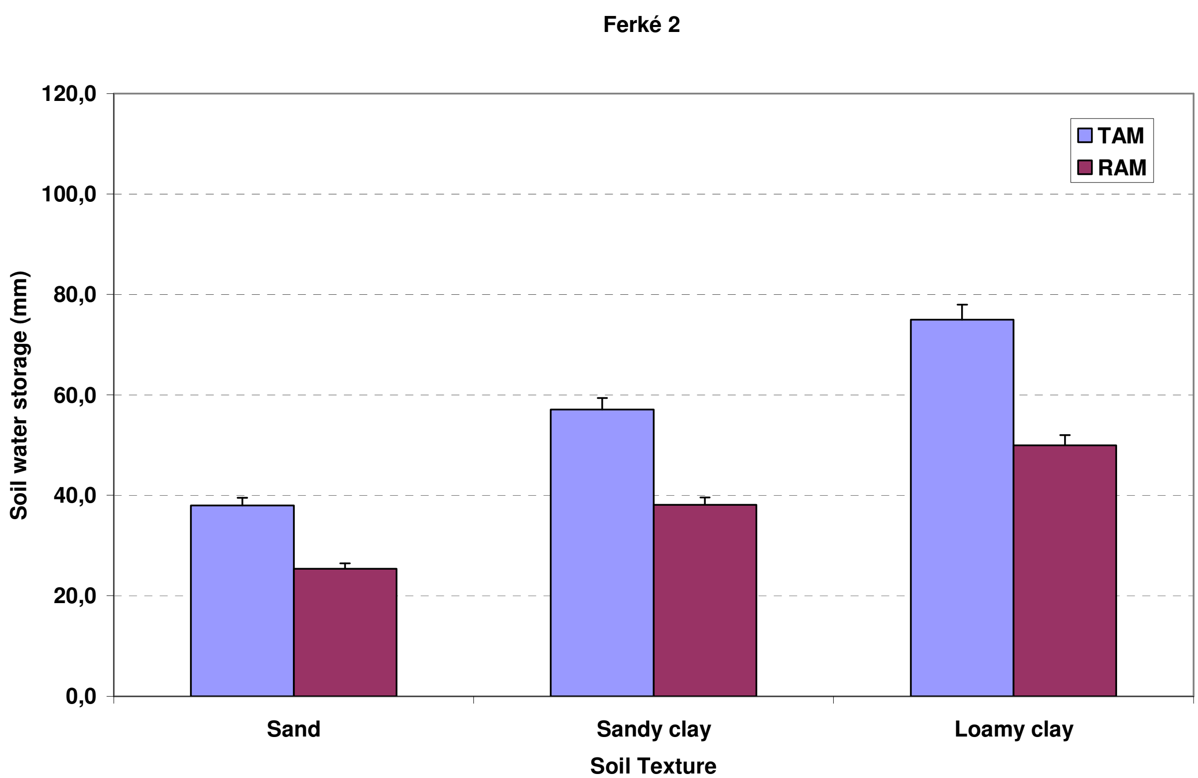

Figure 2: Total and readily available moisture for 3 different soil types in Ferké 2 sugar mill.

Soil water retention curves (or pF curves): Within the soils unsaturated zone a decrease in water content results to an increase of absolute water potential due to increase in capillary as well as adsorption forces on solid articles. The water content-matric potential relation Θ (h) defined as soil moisture characteristic curve is soil type-specific because of influence of the geometry of pores (structure) on capillary forces as well as the specific area of solid particles (texture) on adsorption forces. Under lower matric potential ($0 < pF < 3$) capillary forces and soil structure are predominant whereas under higher matrix potential ($pF > 3-4$) adsorption forces and soil texture are predominant. Nevertheless, the water content – matric potential relationship is not unique as the pF-curves may somewhat differ depending on the soil being under drainage or humidification phase. At a given soil water potential, water contents are higher under drainage phase than under humidification. That hysteresis phenomenon is due to contact angles between capillary forces and solid particles as well as the non-uniform geometry of soil pores with different capillary resistance capabilities (Soutter and Musy, 2006). Soil water has been classified as hygroscopic, capillary and gravitational. Hygroscopic water is on the surface of soil particles and is not capable of significant movement by gravity or capillary forces. Capillary water is that part in excess of the hygroscopic water which exists in the pore space of the soil and is retained against the force of gravity in a soil that permits unobstructed drainage. Gravitational water is that part in excess of hygroscopic and capillary water which will readily move out of the soil if favourable drainage is provided (Babajimopoulis et al, 2007; Ghiberto et al, 2011; Kowalik, 2006). There is no precise boundary or line of demarcation between these three classes of soil water. The proportion of each class depends on soil texture, structure, organic matter content, temperature and depth of soil column considered. Water may also be classified as unavailable, available, and gravitational. Such a grouping refers to the availability of soil water to plants. Gravitational water drains quickly from the root zone under normal drainage conditions. Unavailable water is held too tightly by capillary forces and is generally not accessible to plant roots. Available water is the difference between gravitational and unavailable water.

Field capacity: Field capacity cannot be determined accurately because there is no discontinuity in the curve of moisture content versus time. Nevertheless, the concept of field capacity is extremely useful in arriving at the amount of water available in the soil for plant use. Most of the gravitational water drains through the soil before it can be used consumptively by plants.

In practice, field capacity is usually determined 2 days after irrigation. Therefore, field capacity defines a specific point on the moisture content-time curve. Specifying the time also makes it possible to calculate the water used consumptively by plants while gravitational water is draining from the soil.

Soil moisture is normally between 1/10 and 1/3 atm when the soil is at field capacity. The correct value depends upon the drainage characteristics of the soil and the time after irrigation at which the soil is assumed to reach field capacity. Sandy soils tend to be near 1/10 atm at field capacity while clays tend towards 1/3 atm. For most agricultural soils, a tension of 1/10 atm corresponds more closely than does 1/3 atm to the general accepted values of field capacity determined by moisture content (Hansen *et al*., 1979).

Permanent wilting point: The permanent wilting point is at the lower end of the available range. A plant will wilt when it is no longer able to extract sufficient moisture from the soil to meet its water needs. Temporary wilting will occur in many crops on a windy day, but the plants recover in the cooler portion of that day. Permanent wilting, as well as temporary wilting, depends upon the rate of water used by the plant, the depth of the root zone, and the soil water holding capacity. Permanent wilting point will occur at higher moisture content in a hot climate than in a cool climate. A plant is considered to be permanently wilted when it will not recover after being placed in a saturated atmosphere where little or no consumptive water use occurs. Field estimates of wilting point can often be made by determining the moisture content of soils in which plants have permanently wilted. This method is subject to more error and requires more judgement than field determination of field capacity. Allowance must be made for depth and nature of rooting. For a plant to reach permanent wilting following irrigation will require one week in sands to maybe 4 weeks in clays, and even longer if the plant is deeply rooted (Hansen *et al.*, 1979).

The tension at which permanent wilting occurs can vary from 7 to as high as 40 atm, depending upon rate of consumptive use, crop, salt content of soil, and soil texture. As the temperature and rates of consumptive use increase, permanent wilting will occur at significantly lower tensions and higher moisture contents. The tension in the soil moisture when the soil is at permanent wilting is generally considered to be 15 atm. Whether, in reality, it is 10 or 20 atm makes very little difference, since the change of moisture is slight with rather large changes of moisture tension. As an approximation, the permanent wilting percentage can be estimated by dividing the field capacity by a factor varying from 2.0 to 2.4, depending upon the amount of silt in the soil. For soils of high silt content, 2.4 should be used.

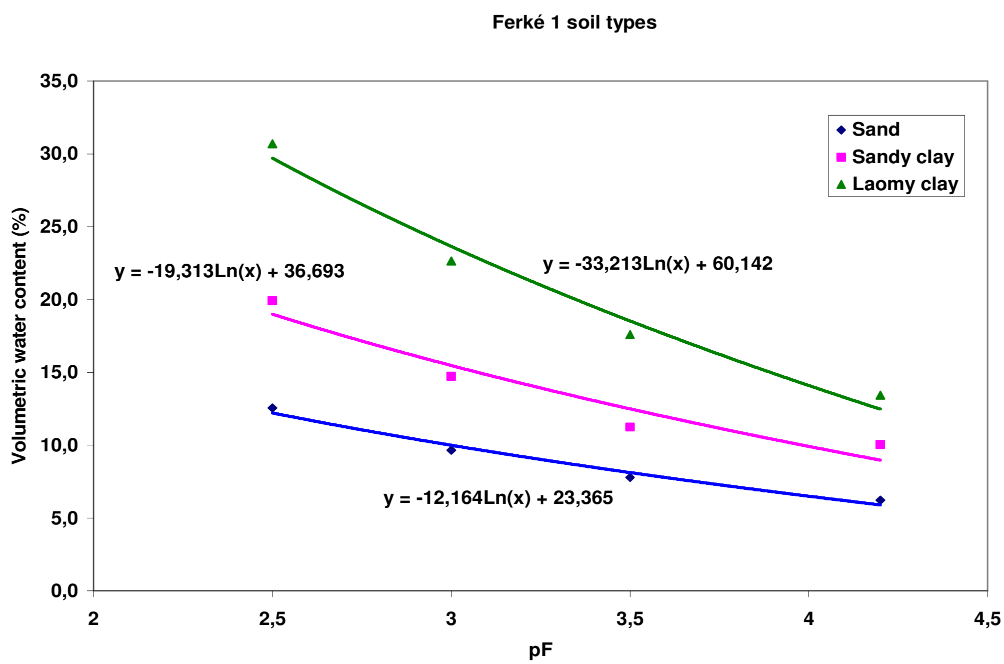

Figure 3. Soil moisture characteristic curves in Ferké 1 sugar mill for three different soil types.

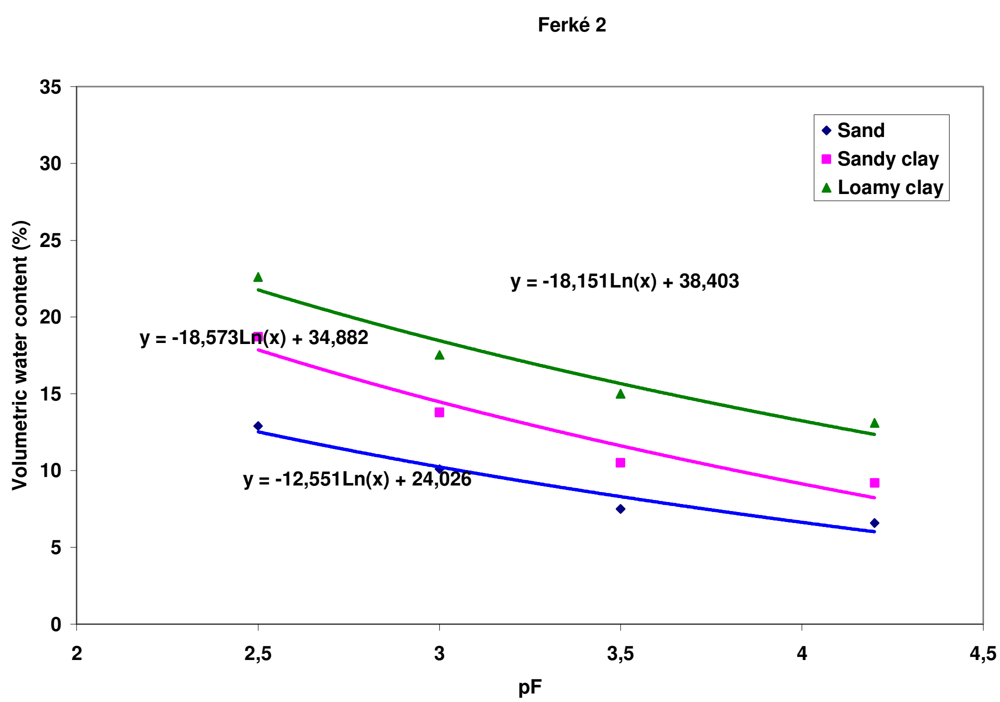

Figure 4: Soil moisture characteristic curves in Ferké 2 sugar mill for three different soil types.

Sugarcane yields as affected by soil tillage practices: Except for the sugarcane plant crop, no significant difference in cane yields resulting from tillage practices was observed over four consecutive cropping seasons. Difference in cane yields observed on the plant crop in favour of the conventional tillage (+16 t/ha) could be explained by better consumptive use of nutrients by sugarcane as a result of much more mineralization of soil organic matter through oxidation with some losses of CO_2 by volatilization or carbonate and nitrate salts by leaching out of the root zone. Therefore, yield decline from plant cane to the first ratoon is very high under conventional tillage (-16 t/ha) compared with the reduced tillage (+3 t/ha). Better use of organic matter over time occurred under reduced tillage with even higher cane yield obtained on the second ratoon (89 t/ha) compared with the conventional tillage (83 t/ha). Cane yields harvested at first as well as third ratoon were statistically equivalent for both tillage practices. The reduced tillage is a key issue which importantly contributes to the reduction of production costs in terms of savings of labour, fuel as well as machinery maintenance. It is one of the 4 pillars in the sugarcane new farming system developed in Australia, namely organic matter conservation (trash blanketing) traffic control, legume break of sugarcane monoculture and reduced tillage. Each of them may individually improve cane yields or impede yield decline, as observed with the reduced tillage, but their combination will improve much more sugarcane productivity and impede production costs for better competitiveness. The Ivorian sugar industry is moving slowly to the right direction except for traffic control of heavy machinery and legume break in sugarcane where quite a lot needs to be implemented.

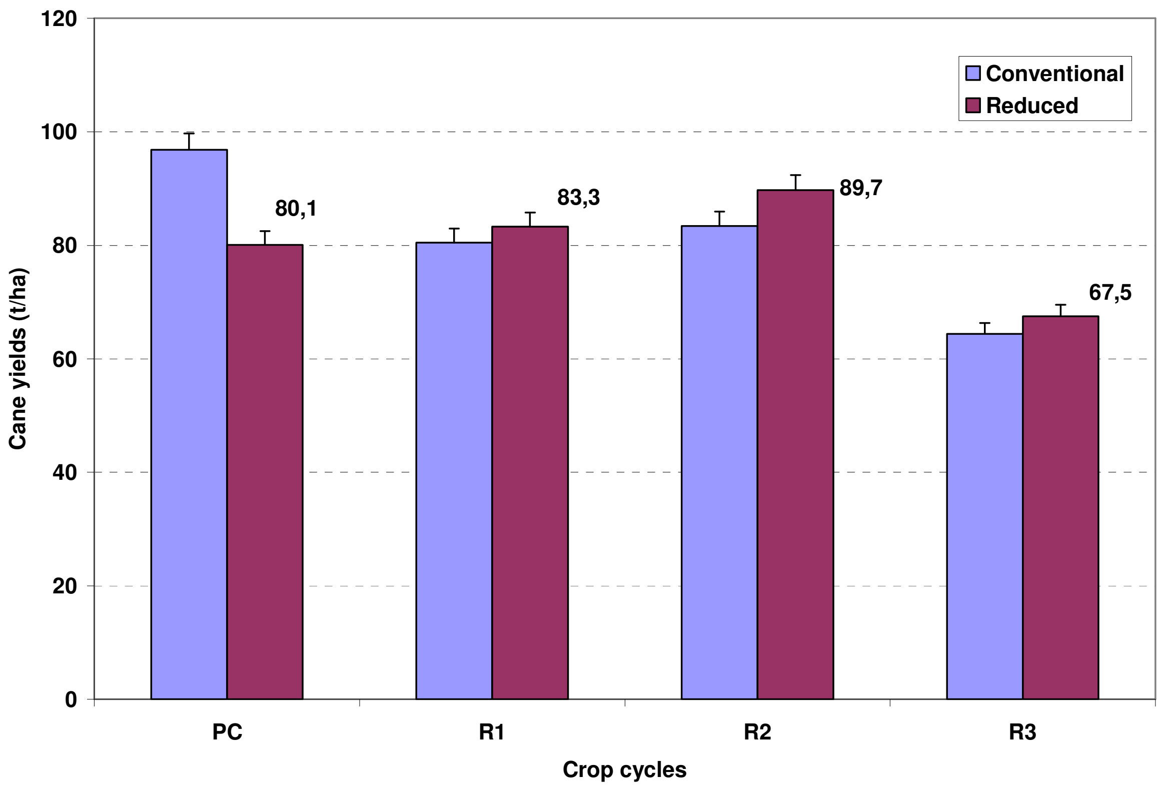

Figure 5: Cane yields of plant crop and three successive ratoons under conventional, reduced tillage, sprinkler irrigation practices in Ferké 1 (28 ha-commercial farm), from March 2007 to January 2011.

CONCLUSION

The results showed that the majority of farmland soils investigated was coarse-textured for about 64 % in Ferké 1 and 85 % in Ferké 2, with a lower to medium water storage capacity (70-89 mm) over 60 cm depth which corresponds to a readily available moisture less than 60 mm. These light soils were much suitable for the practice of minimum tillage which importantly contributes to reduce sugarcane production costs. The other textural categories such as sandy-clay or clay-loam, rather well balanced and less suitable for the practice of reduced tillage without pre-watering, gave medium to high total available moisture (90-110 mm) and therefore a maximum irrigation application rate (or readily available moisture) of 60-70 mm. Except for the sugarcane plant crop, no significant difference in cane yields resulting from tillage practices was observed over four consecutive cropping seasons. The yield decline from plant cane to the first ratoon is very high under conventional tillage (-16 t/ha) compared with the reduced tillage (+3 t/ha). Even higher cane yield was obtained on the second ratoon (89 t/ha) compared with the conventional tillage (83 t/ha).

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