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Soil moisture management and mulch impact on sugarcane yields under irrigated and rainfed conditions in Côte d'Ivoire

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Abstract

Sugarcane cropping in Côte d'Ivoire is facing a rarefaction of water resources, due to the variability of rainfall and their increasingly reduced frequency. Irrigation, which must compensate for this water deficit, is a real source of depletion of water resources. Also, it is not within reach of cane smallholders because of its high cost. Beside the lack of water, the sugarcane manuel harvesting is becoming more and more expensive. Thus, the Ivorian sugar industries are led to turn to the mechanized green harvesting that generates a large amount of mulch now available on cultivated plots. In the interest of sustainable management of water resources and surface water during rains, this study aimed to evaluate the effect of this mulch on the conservation of soil moisture and the sugarcane yield in order to increase water use efficiency and reduce the pressure of its demand. It was conducted at Ferké 1 in northern Côte d'Ivoire, on two experimental plots (rainfed and irrigated). Two treatments were studied (mulch and no mulch). The results showed that mulch retains soil moisture on both cropping systems (23.4 p.c and 10 p.c.) and improves cane stalk length and cane yield in rainfed conditions. In irrigated conditions, no significant differences were observed in cane yield. The management of soil moisture through the use of mulch is therefore an opportunity for development of the rainfed cane in Côte d'Ivoire.

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Introduction

In Côte d'Ivoire, sugarcane plays an important role economically and in terms of food. Its cultivation represents 3.3 p.c of the agricultural sector, provides more than 7000 jobs and contributes to 1 p.c of gross domestic product (GDP). With a yield of around 200 000 tons of sugar in 2014, Côte d'Ivoire has the largest sugar industry in the West African Economic and Monétary Union (WAEMU). About 80 p.c of the yield is used for national sugar consumption and 20 p.c is exported (FAO 2015). In spite of this pride of place held by the crop, sugarcane is confronted with several constraints. Among these is the scarcity of water resources. Indeed, sugarcane is a very demanding plant in terms of water. A water deficit leads to huge losses in yields. Faced with this, compensation methods have been developed, including the selection of drought-resistant varieties and the optimization of the use of water resources. However, the creation of resistant varieties is slow and costly (Kouamé *et al* . 2012). With climate change, rains have become increasingly rare. Moreover, global warming exerts a high pressure on watercourses. Thus, water resources are in constant decline and drought is gaining ground and soil moisture is greatly affected there of (Kouassi 2008). In the Ivorian context, water is the main limiting factor for sugarcane yields, and irrigation is a real source of water depletion (Péné *et al.* 1997). Moreover, it is very expensive and requires a lot of electrical energy. As a result, it is not within the reach of village producers whose plots are under rainfed conditions, with low yields. Under rainfed conditions, the crop depends only on rainfall for its water supply. The water brought by the rain is insufficient to cover sugarcane needs. Furthermore, many losses are caused by surface runoff and intense water evaporation. Thus, water deficit is common under the rainfed system (Péné and Tuo 1996). Because of these climatic characteristics, the available water must be used as efficiently as possible. Thus, soil moisture retention will be possible by avoiding runoff and keeping rainwater as much as possible where it falls. In addition to the lack of water, the labor in charge of maintaining and harvesting sugarcane is becoming increasingly rare and costly.

As a result, sugarcane producers have to resort to mechanized practices such as mechanized green cutting. Today, in the sugar areas of Ferké, more than 33p.c plots are mechanically harvested green. This practice generates a large amount of straw which is now available on cultivated plots. The straw covers the surface of the plots after each harvest and forms a real obstacle against weed infestation. It could be an effective tool capable of increasing water use efficiency and reducing demand pressure (Meridja 2011).

This study aims therefore at assessing the effect of complete mulch on soil moisture conservation and sugar cane yield in the Ferké 1 sugar complex in northern Côte d'Ivoire. It was specifically about :

- assessing the effect of mulch on soil moisture under irrigated and rainfed conditions;
- determining the effect of mulch on tillering and sugarcane stem length;
- demonstrating the influence of mulch on sugarcane yield under irrigated and rainfed conditions;

Material and methods

Expérimental site description

The experiment was conducted at the Ferké 1 sugar complex, on two experimental plots, namely B1-46 and L1-66. These two plots are about 20 km apart. Plot B1-46 was under rainfed conditions while L1-66 was under irrigated conditions. However, both plots were characterized by the same pedoclimatic conditions. The soil is ferralitic remolded with an ocher sandy-clay texture, marked by lateritic induration at 80 cm depth. It is poor in organic matter (1.5p.c) with a more or less acidic pH (6.0) and a low cation exchange capacity in the order of 8 meq/100g (Péné and Koulibaly 2011). The climate of the region of Ferké is dry tropical with two seasons ; a dry season from November to April and a wet season from May to October. The average annual rainfall in this locality is 1600 mm. The rainfall deficit to be filled by irrigation is 700 mm. The dry season is marked by a dry wind (harmattan) which is highly favorable for sugar cane maturation, with daily thermal differences beyond 20°C and a relative air humidity sometimes reaching 30-35 p.c (Péné *et al* . 2010).

Plant material

Two varieties of sugarcane were used in this study, namely M2593/92 planted under rainfed conditions on plot B1-46 and SP711406 planted under irrigated conditions on plot L1-66. Variety M2593/92 originates from Mauritius and was introduced in the Ferké sugar complex in 2007. As for variety SP711406, it originates from Sao Paulo in Brazil. It was introduced in Côte d'Ivoire 1987 (Kouamé *et al* ., 2010).

Technical material

Diviner 2000 of the company Sentek was used for soil moisture measurement during this experiment. It is a portable soil moisture measurement device consisting of a data display console and a portable probe. The display console is a tool for storing and displaying data measured by the probe. It consists of a screen surrounded by a keyboard. The portable probe is a metal rod with a cap and a sensor at its lower end. It is connected to the display console by a cable coming out of its end. For the measurements, we used a diviner with a 70-cm portable probe.

Materials and Methods

Experimental design

The experimental design adopted for each plot was a randomized complete block of two treatments, including complete mulch (PC) and no-mulch (NP), with six repetitions. The treatments were applied on micro-plots of 9 m wide and 40 m long, that is, a total surface area of 360 m^2 (40 m x 1.5 m x 6 rows). On each micro-plot was planted 6 sugarcane rows including 02 border rows on a usable surface area of 120 m^2.

Implementation of the experiment

The experiment was set up after virgin sugarcane harvest. Indeed, it is the mulch obtained after the harvest which made it possible to carry out the trials. Each plot was divided into 02 blocks each of which was subdivided into 06 micro-plots including 03 micro-plots for each treatment.

The mulch was kept as it was on the ground after virgin sugarcane harvest so as to form the “complete mulch” treatment. The “no-mulch” treatment was achieved by removing the mulch produced virgin cane harvest. This helps simulates the burning conditions.

Set up of diviner 2000 access tube

In order to measure soil moisture, diviner 2000 access tubes were set up in the soil. In both irrigated and rainfed plots, 04 access tubes were set up in each treatment, that is, 02 tubes on the row and 02 tubes on the sugarcane inter-row.

For the setup of diviner 2000 access tube, a hole was dug into the soil using a volume auger. Then some cement was prepared to fix the tube into the soil. The latter consisted of a mixture of 04 volumes of kaolinite and 01 volume of gray cement for 05 volumes of water. The 60-cm hole was filled to one-third of its volume, then the diviner's access tube was slowly pushed in through its sealed end. This caused an ascent of the cement, chasing any column of air around the access tube. Finally, the tube cap was installed by applying 03 silicone rings around the outside of the access tube over 1 cm approximately so as to ensure its adhesion to the tube.

Parameters measured

Soil moisture

Moisture measurements were performed by introducing the portable probe into the tubes set up in the soil. The probe measured the water content of the soil in each layer of 10 cm deep through the soil profile.

Diviner 2000 is a capacitive probe whose operation is based on the principle of soil dielectric permittivity variations. The probe introduced into the access tube generates an electric field in the soil. As the water molecule is polarized, water molecules that are not bound to soil particles rotate to align with electric field lines. This rotation requires energy, which is stored as potential energy in the aligned water molecules. The more water is in the soil, the more energy is stored, and the higher is the apparent permittivity of the soil.

The probe provides the volume of water contained in soil pores in millimeters. Volumetric soil moisture is calculated according to the formula below :

$$Q\ (mm) = L \times e \times 0{,}1$$

With :
- **Q** : Volumetric soil moisture at a given depth (mm)
- **L** : Gross value of soil moisture measured by diviner 2000 probe
- **e** : Width of the layer in which the measurement is made

Moisture differences between the mulch and no-mulch

The moisture differences between themulch and no-mulch indicates the amount of water retained in the soil thanks to mulch. In order to determine this amount of water, moisture differences were calculated by making the difference between the water content of the soil covered with mulch and that of the uncovered soil; That is-

$$\text{Moisture difference (p.c)} = \frac{(Q_{\text{mulch}} - Q_{\text{No-mulch}})}{Q_{\text{No-mulch}}} \times 100$$

Q_{mulch} (mm) : volumetric moisture of the soil covered with mulch at a given depth

$Q_{\text{no-mulch}}$ (mm) : volumetric moisture of the soil non-covered with mulch at a given depth

Sugarcane tillering

Tillering was assessed by counting sugarcane stems 10 m apart on each of the two central rows. The number of stems/ha was calculated using the following formula:

$$\text{Tillering (stalks/ha)} = \frac{\text{Number of stalks x 6667}}{20}$$

With 6667 (m): The linear length of one hectare of sugarcane on a plot having a length of 432m

Stalk length

Stalk length was measured during the annual cycle of sugarcane cultivation. It began when stem internodes began to form, that is, after three and a half months corresponding to the "Boom stage" phase and ended in the tenth month of growth, when the sugarcane plots have become difficult to access. To this end, 10 sugarcane stems, randomly selected from the two central rows considered for tillering assessment, were marked with blue plastic bags. Then, the measurements were made using a tape measure 10 days apart.

Then, the average height of the stems per micro-plot (Hm), was calculated by dividing the sum of the heights (Sh) of the stems measured by the number of stems considered (N).

$$Hm = \frac{Sh}{N}$$

Finally, the average height of stems per treatment (Ht) was calculated by dividing the sum of average heights of sugarcane stems per micro-plot (SHm) by the number of repetitions (r) of each treatment.

$$Ht = \frac{SHm}{r}$$

Sugarcane yield

The trials were harvested after 12 months. The usable rows were cut manually and the sugarcane stems were grouped by micro-plot, depending on the treatment performed. Then, the heaps of sugarcanes obtained were tied with two strings. The weight of sugarcanes was determined using a weight scale suspended from the hook of a mechanical loader (Fig. 6). Finally, sugarcane yield was calculated according to the following formula:

$$\text{Sugarcane yield (t/ha)} = \frac{\text{Sugarcane weight (kg) x 10}}{\text{Usable surface area (m2)}}$$

Statistical analyses

For all the treatments used, each result corresponds to the average of 6 repetitions. An analysis of variance was applied to the parameters measured and in case of significant effect of the studied treatment, the comparison of the averages was carried out according to the Newman-Keuls test at 5p.c threshold using the STATISTICA version 7.1 software.

Results

Evolution of soil moisture depending on soil depth

The evolution of soil moisture in the irrigated and rainfed system is presented in Fig. 1, 2 and 3. Fluctuations in the evolution of soil moisture were more marked in the 0-30 cm horizon than that of 30-60cm. In the irrigated system, soil moisture was subject to the same variations in the soil covered with complete mulch and the soil non-covered with mulch at different depths.

However, the soil moisture level under complete mulch was always above that of the soil not covered with mulch. This difference is more noticeable in the dry season. Under rainfed conditions, the difference between soil moisture evolution under complete mulch and under no-mulch was greater. In the upper soil horizon, soil moisture varied abruptly with water inflow (Fig. 4, 5 and 6). It increased quickly after a rain on both soils. However, it decreased sharply in the absence of rain in uncovered soils and slowly under complete mulch. Thus, between two rainy episodes, soil moisture was conserved for a long period at an acceptable level under complete mulch while it was lost more rapidly in soils non-covered by mulch (Fig. 7 and 8). In the soil layer of 30-60 cm deep, soil moisture variations depending on time and water inflow were less significant. However, they were more noticeable in uncovered soils than under complete mulch.

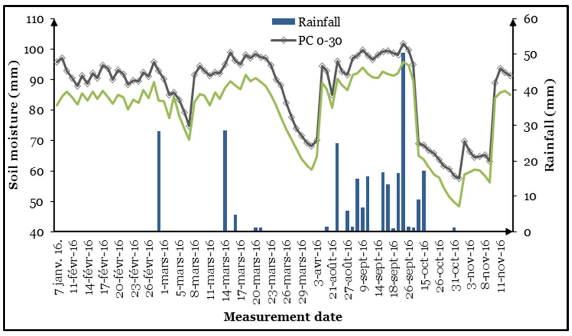

Fig. 1. Evolution of soil moisture under irrigated system at 0-30 cm deep.

NP : Treatment 1 = no-mulch PC :

Treatment 2 = complete mulch

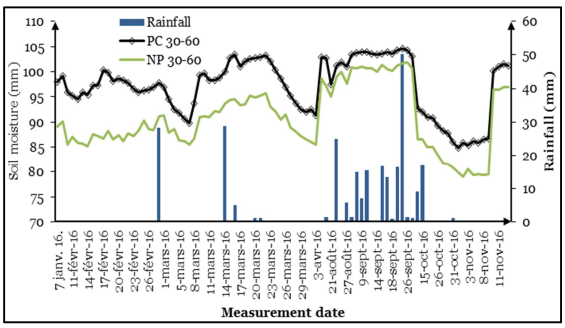

Fig. 2. Evolution of soil moisture under irrigated system at 30-60 cm deep.

NP: Treatment 1 = no-mulch

PC: Treatment 2 = complete mulch

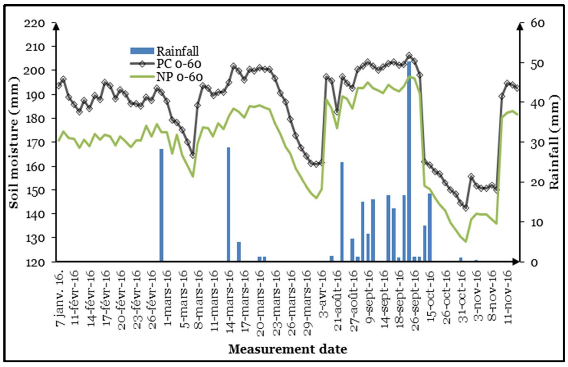

Fig. 3. Evolution of soil moisture under irrigated system at 0-60 cm deep.

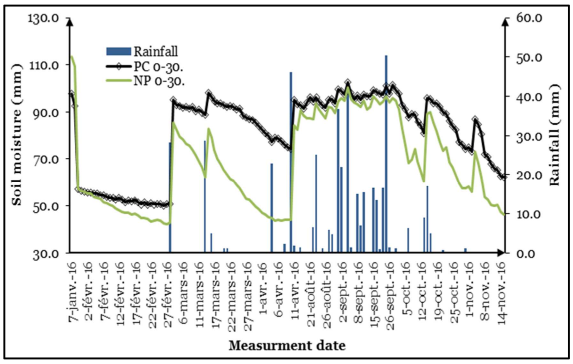

Fig. 4. Evolution of soil moisture under rainfed system at 0-30 cm deep.

NP : Treatment 1 = no-mulch

PC : Treatment 2 = complete mulch

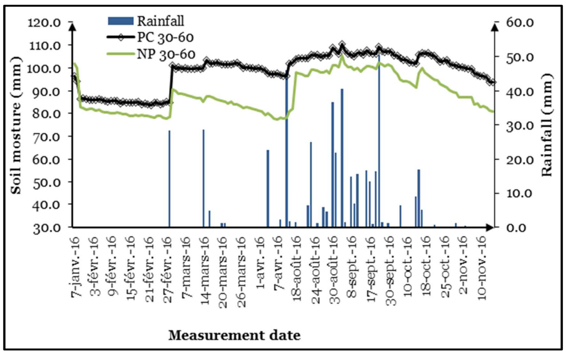

Fig. 5. Evolution of soil moisture under rainfed system at 30-60 cm deep.

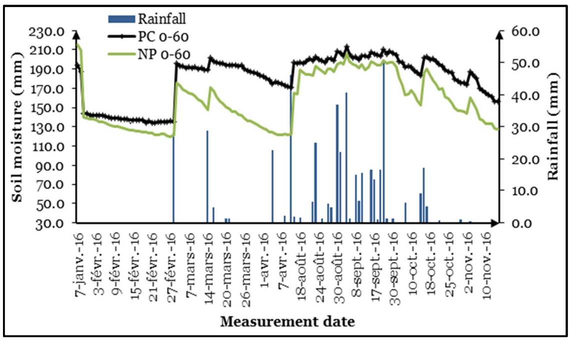

Fig. 6. Evolution of soil moisture under rainfed system at 0-60 cm deep.

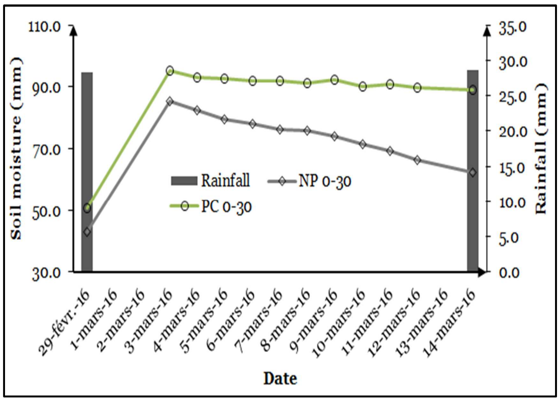

Fig. 7. Evolution of soil moisture between two rainy episodes under rainfed system at 0-30 cm deep.

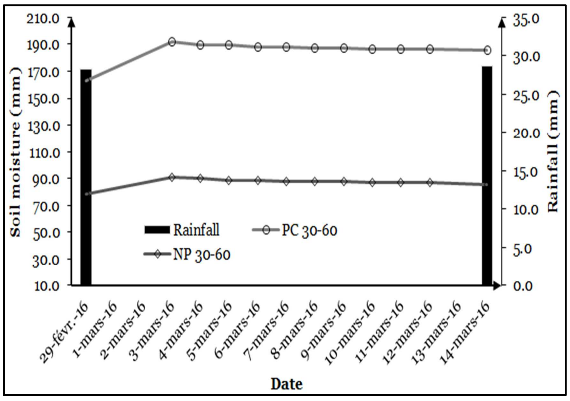

Fig. 8. Evolution of soil moisture between two rainy episodes under rainfed system at 30-60 cm deep.

Moisture differences between complete mulch and no-mulch

Moisture differences between complete mulch and no-mulch are shown in Fig. 9 to 12. Under irrigated conditions, moisture differences between complete mulch and no-mulch vary around an average of 8.1p.c over the entire profile considered with a maximum of 13.5p.c in the dry season and a minimum of 3.1p.c in the rainy season. In the 0-30cm deep layer, the complete mulch made it possible to retain on average 10p.c of soil moisture compared to no-mulch.

Moisture differences were higher in the dry season when they reached 19 p.c against 1.6p.c in the rainy season. In the 30-60cm deep layer, moisture differences that complete mulch helped retain compared to no-mulch were less significant. They varied around an average of 7.22 p.c with a maximum of 15.72 p.c in the dry season and a minimum of 2 p.c in the rainy season (Fig. 9 and 10).

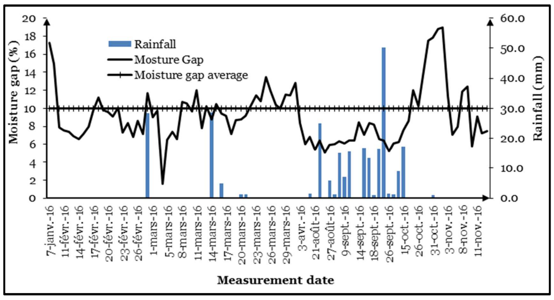

Fig. 9. Evolution of soil moisture differences between complete mulch and no-mulch under irrigated conditions at 0-30 cm depth.

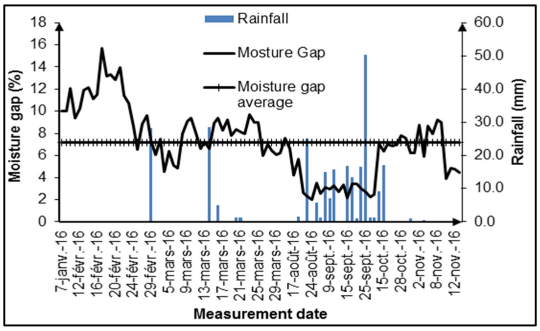

Fig. 10. Evolution of soil moisture differences between complete mulch and no-mulch under irrigated conditions at 30-60 cm depth.

Under rainfed conditions, humidity differences were more significant. In the 0-30cm deep layer, complete mulch made it possible to retain an average 23.4 p.c of soil moisture compared to no-mulch. The effect of mulch is also more significant in the dry season when moisture differences reach up to 81.1 p.c of soil moisture compared to no-mulch. In the 30-60 cm deep layer, complete mulch made it possible to retain 11.7 p.c of soil moisture compared to no-mulch. The effect of mulch remained maximum in the dry season with differences of about 26 p.c compared to no-mulch (Fig. 11 and 12).

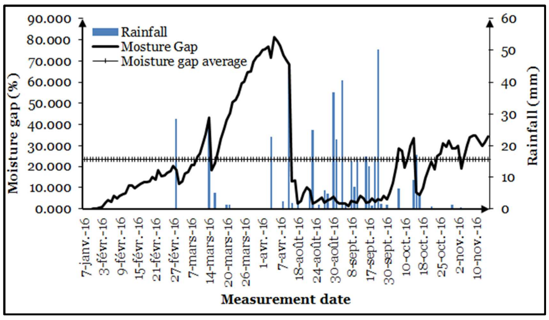

Fig. 11. Evolution of soil moisture differences between complete mulch and no-mulch under rainfed conditions in layers at 0-30 cm depth.

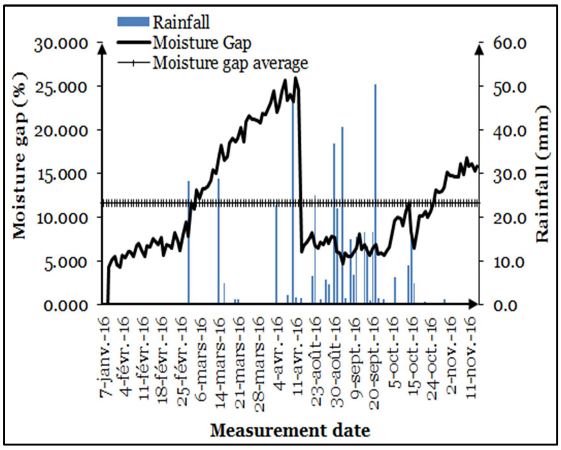

Fig. 12. Evolution of moisture differences between complete mulch and no-mulch under rainfed conditions in layers at 30-60 cm depth.

Effect of complete mulch on sugarcane tillering

The tillering obtained on the different plots is presented in Fig. 13. No significant difference was observed in the stems counted on the soil covered with mulch and the uncovered soil in both irrigated and rainfed conditions. Statistical analyses of these results revealed a single homogeneous class on both cropping systems.

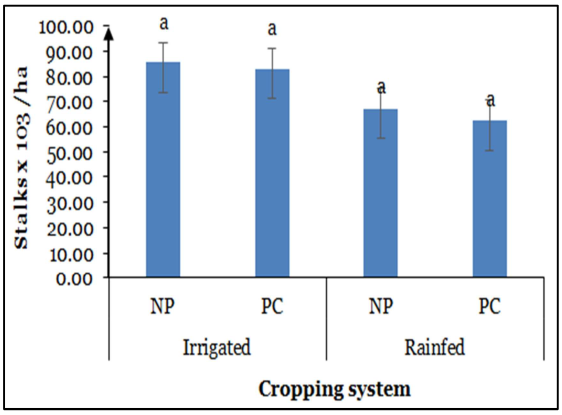

Fig. 13. Sugarcane stalks number depending on irrigated and rainfed systems.

NP: treatment 1 = no-mulch

PC: treatment 2 = complete mulch

Effect of complete mulch on sugarcane height

The statistical analysis of sugarcane stem length showed a significant difference in rainfed cropping system. Complete mulch provided stems with an average length of 202.93 cm compared to 186.67 cm obtained on the soil without mulch (Fig. 14).

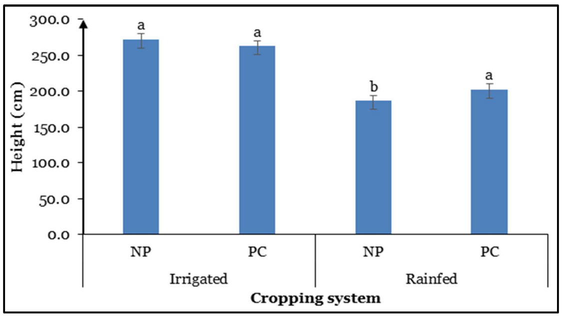

Fig. 14. Height of sugarcane stalks depending on on irrigated and rainfed systems.

NP: treatment 1 = no-mulch

PC: treatment 2 = complete mulch

Effect of complete mulch on sugarcane yield

The statistical analysis of yield data obtained showed a significant effect of mulch under the rainfed system. Complete mulch treatments recorded the highest yields at 57.67 t/ha. The lowest yields were observed on non-mulched plots with 44.44 t/ha. In rainfed conditions, mulching increases cane yield about 29.8 p.c. Under irrigated regime, no significant difference appeared between sugarcane yields obtained on soils covered with complete mulch and non-mulched soils (Fig. 15).

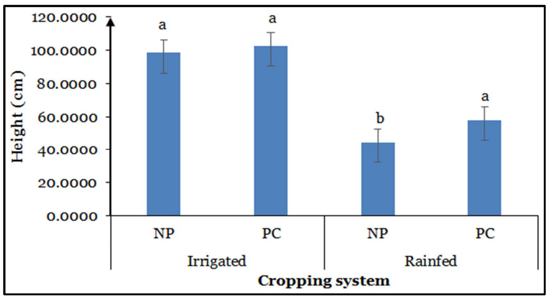

Fig. 15. Sugarcane yield according to irrigated and rainfed systems.

NP : treatment 1 = no-mulch

PC : treatment 2 = complete mulch

Discussion

Complete mulch treatments showed significant effects on soil moisture. Indeed, unlike the soil covered by mulch, the soil without mulch is exposed to evapotranspiration and runoff. This justifie why the moisture level of the soil with complete mulch is always higher than that of the soil without mulch. Our results are consistent with those of Sadeghi and Bahrani (2009) who showed that the humidity of a covered soil is always greater than that of a bare soil.

Under irrigated conditions, the effect of mulch on soil moisture was less significant. This is due to the fact that water deficit is continuously compensated for by irrigation. Indeed, on the Ferké 1 sugar complex, sugarcane irrigation is conducted according to the daily meteorological data and makes it possible to me*et al* l the needs of the crop. Irrigation can help me*et al* l the water needs of sugarcane. Complete mulch can help retain up to 10p.c of soil moisture compared to no-mulch under irrigated conditions. Despite this, no significant difference was observed for tillering, stem height, sugarcane yield, and extractable sugar yield on both treatments. This indicates that such amount of water retained by mulch and lost by bare soil has not been recovered by the crop. It therefore constitutes a surplus of water whose absence or presence does not affect the sugarcane yield. Thus, in the presence of mulch, the amount of water brought by irrigation could be reduced by 10 p.c. Our results are in accordance with those of Lal *et al* . (2007) who showed that mulch helps reduce irrigation of cultivated plots.

Under rainfed conditions, the crop only benefits from water inflow by rain. As a result, the effect of mulch on soil moisture is more significant. In fact, complete mulch makes it possible to retain on average 23.4 p.c of soil moisture compared to no-mulch. This great performance could be explained by the fact that mulch reduces runoff and evapotranspiration. Indeed, after a rain the mulch layer is a real obstacle against the runoff. It behaves like a carpet that holds water in place and releases it gradually. Our results are consistent with those of Derpsch *et al* . (1991) who showed that mulch dampens the kinetic energy of raindrops and allows water to spread slowly over the soil surface. Moreover, mulch acts as a thermal buffer and forms a screen to the action of the sun on the soil. Thus, it might help reduce water loss and keep it longer in the soil. This explains why moisture differences compared to no-mulch in favor of complete mulch would reach up to 81.1p.c in the dry season. Our results are in accordance with those of Lal *et al* . (2007) who found that mulch prevents water evaporation into the atmosphere by keeping the soil temperature at an optimal level and slowing sugarcane transpiration during the hot season. Furthermore, mulch also prevents weed infestation and reduces weed competition for water resources. Thus, the water brought by rainfalls is entirely at the disposal of sugarcane. Our results are in accordance with those of Antoir *et al.* (2016) who achieved similar results by working on sugarcane in Réunion. The significant difference observed under rainfed conditions between the heights of stems recorded on soil covered with complete mulch and soil without mulch is therefore due to the availability of water in the soil for sugarcane. Indeed, water is an essential element for plant growth. It is not only essential to the plant, as a nutrient, but also to its mineral nutrition. Thus, by maintaining soil moisture, mulch makes available the mineral elements necessary for sugarcane growth. Our results coincide with those of Ouedraogo (2014) who, while working on sorghum obtained an increase in plant height on mulched plots compared to soils without mulch. Furthermore, mulch left in the field brings a large amount of organic matter to the soil. This activates the life of the soil and protects it against the harmful action of ultraviolet radiation. The activity of the latter is at the origin of a porous and well ventilated structure. Thus, mulch creates a favorable environment for root proliferation and increases the bioavailability of nutrients in the soil (Sadeghi and Bahrani, 2009). The mulch allows a better conservation of soil structure thanks to an increased stability of the aggregates and a decrease of sealing crust after heavy rains (Stewart, 2007). The lack of statistical difference, under rainfed conditions, between sugarcane tillering on plots with complete mulch and plots without mulch shows that water is not a determining factor in sugarcane tillering. Indeed, tillering is dependent on minerals, in particular nitrogen supply. Our results are in accordance with those of Fillols and Chabalier (2007) who showed that a nitrogen deficiency considerably reduces sugarcane tillering. Moreover, Dogget (1988) showed that the tillering ability of sorghum depends mainly on nitrogen supply. Since mulch does not influence tillering, the significant difference between sugarcane yields obtained in rainfed system might be due to the effect of mulch on sugarcane stem height. Thus, a good growth of stems when sugarcane is well supplied with water leads to an increase in yields. The accumulation of the beneficial effects of mulch results in a stabilization of yields at a high level (Lahmar *et al* . 2006 ; Lahmar and Bouzerzour, 2011). Like tillering, extractable sugar yield does not depend on wateravailability. Moreover, during the accumulation of sucrose in its stems, sugarcane requires water deficit. Thus, separation conditions should be studied so as to optimize the effect of mulch on extractable sugar yield on both irrigated and rainfed plots harvested in green.

Conclusion

Mulch helps keep soil moisture and continue sugarcane water supply until the next inflow of water. Under rainfed and irrigated conditions, the soil moisture level with complete mulch treatment was always kept above that of the no-mulch treatment. These beneficial effects of complete mulch on soil moisture are more significant under rainfed conditions where soil moisture differences compared to no-mulch reach up to 81.12 p.c in the dry season. Under irrigated conditions, the effect of mulch is also considerable with moisture differences of about 10p.c compared to no-mulch. Complete mulch therefore constitutes an important tool for the sustainable management of water resources in that it ensures a good recovery of rainfall received by crops both under rainfed and irrigated conditions. Moreover it helps reduce the quantities of water brought by irrigation without affecting the yield. Thus, mulch could help reduce sugarcane production costs by reducing the energy spent on irrigation.

Mulch also helps improve the sugarcane yields under rainfed conditions. This is attributable to water availability, soil aeration and the supply of nutrients essential for the growth of sugarcane stems. It is therefore an asset for the sector and a real opportunity for village producers. In addition to these important properties, mulch also helps reduce weed competition and therefore reduces the cost of herbicide use.

It also protects soil biodiversity and increases its activity. Furthermore, mulch greatly reduces the superficial flow of water (runoff) and protects the soil against erosion. Thus, mulch helps protect the environment, increase yields and reduce sugar production costs.

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Conflict of interest: The authors declare that they have no conflict of interest.

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