PERFORMANCES OF SUBSURFACE DRIP IRRIGATION FOR MAIZE UNDER MEDITERRANEAN AND TEMPERATE OCEANIC CLIMATE CONDITIONS

PERFORMANCE DU GOUTTE-A-GOUTTE ENTERRE POUR L'IRRIGATION DU MAÏS SOUS CLIMATS MEDITERRANEEN ET OCEANIQUE TEMPERE

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ABSTRACT

This paper aims at evaluating the grain yield (GY) and Irrigation Water Productivity (IWP) performances of subsurface drip irrigation (SDI) for maize under a Mediterranean (Lavalette station) and temperate Oceanic climatic (La Mirandette station) conditions. Irrigations were conducted to fulfil 80-85% of the maximum crop requirements using SDI compared to fully-irrigated sprinkler treatments (SI). Dripline spacing used for SDI were "narrow" of 100 cm (SDI-100) and 120 cm (SDi-120) and "large" spacing of 150 cm (SDI-150) and 160 cm (SDI-160) at La Mirandette and Lavalette stations, respectively. The results indicate that reducing irrigation quantities by 15-20% with SDI significantly affected GY at Lavalette station but had less effect at that of La Mirandette. SDI slightly increased IWP compared to sprinkler-irrigated treatments at Lavalette (8% increase) whereas it had less and erratic effect in the case of La Mirandette, depending on rainfall. We conclude that under both climatic conditions, deficit irrigation with SDI would not allow to significantly increasing water productivity for maize compared to the more conventional technique of sprinkler without impacting yield.

RÉSUMÉ

L'objectif de cette étude est d'évaluer la production de grain (GY) et la productivité de l'eau de l'irrigation (IWP) du goutte-à-goutte enterré (GGE) pour la production de maïs sous climats méditerranéen (site Lavalette) et océanique tempéré (site La Mirandette). Le GGE a été utilisé pour mener des irrigations déficitaires correspondant à 80-85% de l'évapotranspiration maximale de la culture, en comparaison avec des traitements pleinement irrigués par aspersion. Deux espacements de lignes de goutteurs ont été utilisés, de 100 et 120 cm (étroit) et de 150 et 160 cm (large), installés respectivement à La Mirandette et à Lavalette. Les résultats indiquent que l'irrigation déficitaire par GGE affecte significativement le GY de maïs à Lavalette mais son impact est bien plus limité à La Mirandette. Le GGE a légèrement augmenté la IWP en comparaison avec l'irrigation en aspersion sur le site de Lavalette (8% d'augmentation) tandis que son effet sur l'IWP à La Mirandette n'a pas connu une tendance systématique et dépendait des cumuls de précipitation. Cette étude indique que le choix de l'irrigation déficitaire en GGE ne permettrait pas d'augmenter d'une manière significative et systématique la productivité de l'eau de l'irrigation sans avoir des impacts négatif sur le rendement.

Keywords: Subsurface Drip Irrigation, Sprinkler Irrigation, Comparative analysis, Water Productivity.

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1. Introduction

During last decades, drip irrigation (DI) has gained wide attention as one potential solution to water scarcity **(Molden and Oweis, 2007)**, both from the scientific community **(e.g. Camp, 1998; Ayars et al., 2000; Lamm et al., 2011)** and from policy makers community **(Venot et al., 2014)**. As a result, surfaced equipped by this technique have known a remarkable increase since the late 90's in the USA **(Camp, 1998)** reaching 59% between 2003 and 2008 **(Lamm et al., 2012)**. Despite the noticeable success this technique has had for irrigating commodity crops in the USA, the idea of adapting this technique to the Mediterranean Region, a typical water scarce area, has known little success. In the Mediterranean region, only shy attempts to adapt this technique have been observed during the last decade. A look through the agricultural national surveys[4] of the principal Mediterranean Maize producers - in an increasing order, Spain, Turkey, Egypt, Italy and France **(according to FAOSTAT, 2013)** - reveal that maize surfaces irrigated by DI technique represent a negligible part from the irrigated surfaces landscape.

Attempts to replace conventional irrigation techniques, especially furrow and sprinkler irrigation, with DI are ongoing in the Mediterranean Region, mainly in Turkey **(e.g. Yazar et al. 2002; Bozkurt et al., 2006; Kuscu et al., 2013; Karasahin,2014)** in Spain **(Arbat et al., 2013; Couto et al., 2013)**, and in Italy **(e.g. Ben Nouna, 2000** and **di Paolo & Rinaldi, 2008)**. The results of these studies are promote generally a decrease in water use, reaching as much as 55% compared to the furrow technique, all with assuring an increase in grain yield of 15-23% **(Yazar et al. 2002)**. Surprisingly, such experimental research on the performances of DI, and more particularly of subsurface drip irrigation (SDI), are lacking for France, the largest maize Mediterranean producer **(FAOSTAT, 2013)** despite the fact that large surfaces cultivated with maize are situated in the southern and south-western regions were summer water deficits are far from being uncommon.

This study aims at performing a comparative analysis of the agronomic performances (grain yield and irrigation water productivity) of SDI and sprinkler systems for maize production under a semi-arid Mediterranean and temperate Oceanic climatic conditions. Results showed hereafter were recorded in 2012 and 2013 growing seasons at two agronomic stations, Lavalette and La Mirandette.

2. Materials and Methods

Lavalette station is located at the IRSTEA experimental site, near Montpellier city in the South of France (43°40'N, 3°50'E, 30 m above MSL). The soil developed from alluvial deposits (Lez River) and classified as Inceptisol (USDA taxonomy). Soil is deep loam (20% clay, 47% silt, 33% sand) with an average holding capacity of 180 mm m^{-1} **(Khaledian et al., 2009)**. Dry bulk density varies from 1.65 g cm^{-3} in top layers to 1.50 g cm^{-3} in deeper layers. The climate is Mediterranean semi-arid whereby from the 770 mm of the annual rainfall (22 years average) only 245 mm occur during the growing season from mid-April to mid-September, while the reference evapotranspiration (ET_{ref}) during the same period raises to 633 mm.

La Mirandette station is located at the CACG[5] experimental site, near Auch city (43°26'N, 0°34'E, 221 m above MSL) in the South-West of France in a region densely cultivated with maize. The soil developed from erosion deposits, classified as Neoluvisol (USDA taxonomy). Soil is loam sandy-clay (27% clay, 44% silt and 29% sand) with an average holding capacity of 130 mm m^{-1} and a dry bulk density going from about 1.31 g cm^{-3} in top layers to 1.75 g cm^{-3} in deeper layers that can present some ferric and manganese concretions. The climate is characterized as temperate Oceanic. The 30-year average annual rainfall totals 975 mm of which 300 mm come during the maize growing season from May till October whereas the ET_{ref} totals 635 mm for the same period, which oblige farmers to systematically irrigate crops.

The experimental trials were similar at both sites and consisted in two irrigation techniques and two irrigation levels. At Lavalette station, irrigation equipments used were RainGun Irrigation (RGI) and SDI with two different drip lines lateral spacing, 160 cm (SDI-160) and 120 cm (SDI-120). Drip lines were buried to a depth of 35 cm. At La Mirandette station, the irrigation techniques were Sprinckler Irrigation (SPI) and SDI with two different drip lines lateral spacing, 150 cm (SDI-150) and 100 cm (SDI-100). Drip lines were setup deeper at 45 cm.

[4] See for instance Magrama, 2013 (Spain), ISTAT, 2012 (Italy) , Agreste, 2012 (France)
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The two irrigation levels aimed at fulfilling 85-90% and 100% of the maximum crop evapotranspiration (ET_c) calculated from ET_{ref} and FAO crop coefficients for maize **(Allen et al., 1998)**. Rainfed treatments (RF) completed the experimental layout at both sites for the evaluation of irrigation performance indicators as detailed hereafter.

On both sites, irrigation events were triggered once the soil matric potential reached -600 cm. Irrigation depths ranged between 20 and 30 mm under RGI and between 10 and 20 mm under SDI. At Lavalette, spray irrigation (10-15 mm) was applied to SDI plots to ensure germination at both years. Irrigation events were then scheduled differently for RGI and SDI treatments according to the growth stages attained by each treatment. RGI treatments where only irrigated under calm or light wind conditions (wind speed < 2 m s^{-1}) in order to avoid irrigation distortion. Irrigation schedule was stopped when grain humidity reached 45-50%.

For spray irrigation (RGI at Lavalette and SPI at La Mirandette station) a set of manual rain gauge (5) was installed over the experimental plots to monitor and check water dose as well as irrigation uniformity. For SDI plots, volumes of water applied were manually recorded through water meters and the watering uniformity was checked through a set of manometer probes installed along the network.

Grain yield (GY) [t ha^{-1}] and irrigation water productivity (IWP) [kg m^{-3}] were used as indicators to evaluate the performances of both RGI and SDI techniques. IWP is calculated as IWP = (GYir-GYRF) / IR, where GY_{ir} and GY_{RF} are grain yields of irrigated and rainfed treatments, respectively, and IR is total irrigation.

For both growing seasons, the main patterns of rainfall, ET_{ref}, irrigations and agronomic practices of the two agricultural research stations are summarized in Appendix 1 and 2 respectively.

3. Results and discussion

The experimental results are shown in Figure 1 and the main comments are summarized in the following points.

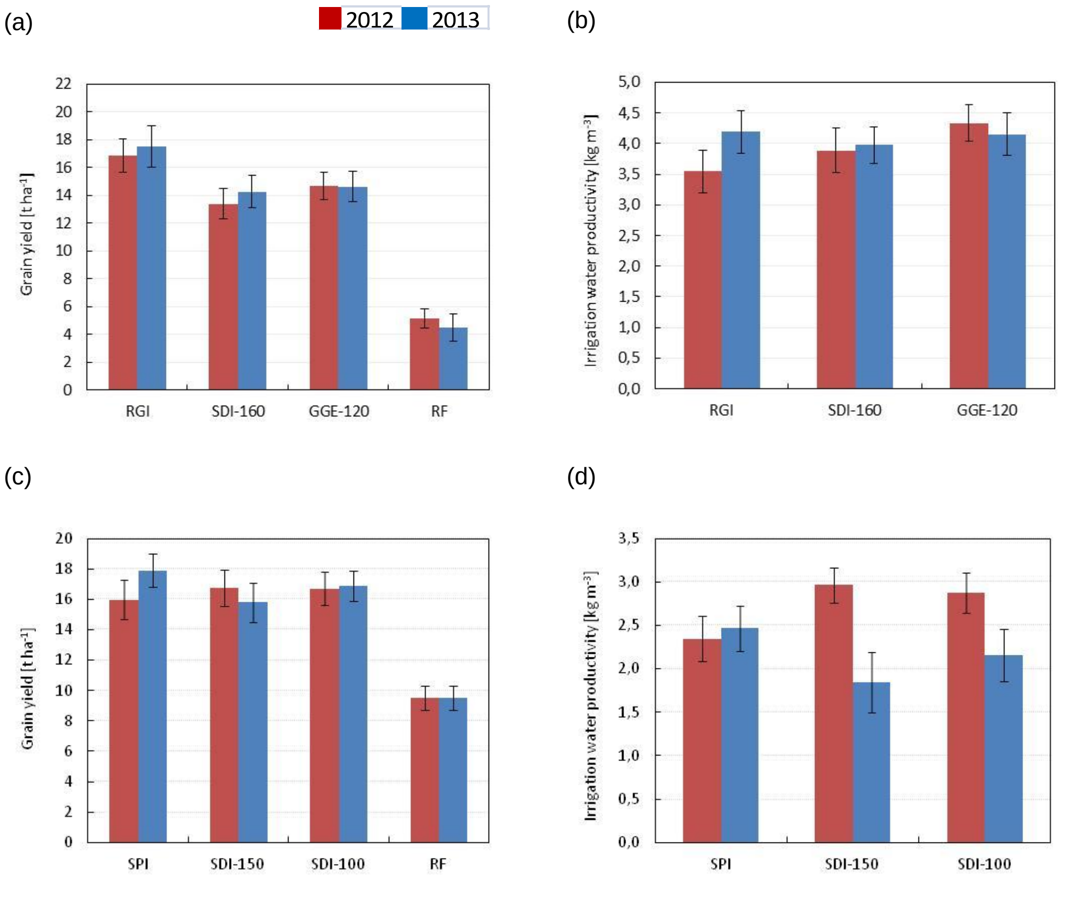

Figure 1: Grain maize yield [t ha^{-1}] and irrigation water productivity [kg m^{-3}] recorded in 2012 and 2013 at Lavalette (a-b) and La Mirandette (c-d) experimental stations, using both sprinkler (RGI/SPI) and subsurface drip irrigation (SDI) systems.

1. Using SDI with 10-15% water deficit led to a net decrease in GY. This decrease was more pronounced under the Mediterranean conditions of Lavalette compared to the temperate Oceanic conditions prevailing at La Mirandette.

In both years at Lavalette, grain yield was reduced by 3.2 to 3.5 t ha^{-1} using SDI compared to the fully irrigated RGI treatment (14.3 t ha^{-1} in average using SDI compared to 17.2 t ha^{-1} using RGI). In contrast, maize yields at La Mirandette station were lightly affected by irrigation water deficit. Only in 2013 grain yield decreased of 2.1 t ha^{-1} in comparison to SPI (16.3 t ha^{-1} in average for SDI compared to 17.9 t ha^{-1} for SPI). The more favourable rainfall conditions under the oceanic transition climate suppressed the imposed irrigation deficits using SDI. Such good growing conditions were clearly reflected by the rainfed yield treatment, which averaged 9.5 t ha^{-1} at La Mirandette compared with only 5.2 t ha^{-1} in 2012 and only 4.5 t ha^{-1} in 2013 at Lavalette station.

2. SDI tends to increase IWP in Mediterranean climate conditions but not in Oceanic ones, especially if fertigation is used.

SDI lightly increased IWP at Lavalette in both years compared to RGI (4.3 kg m^{-3} in average for SDI compared to 4.0 kg m^{-3} for RGI) whereas it only increased in 2012 at La Mirandette station (3.0 kg m^{-3} in average for SDI in comparison with 2.3 kg m^{-3} for SPI). In 2013, IWP was reduced using SDI technique (2.0 kg m^{-3} in average for SDI compared to 2.5 kg m^{-3} for SPI). Such result could be explained by the change in the fertilization method. Indeed, in 2012 N fertilizer was applied by side dressing at the beginning of the growing cycle, while in 2013, the fertigation method was applied. The high rainfall amounts in 2013 (341 mm) may have thus contributed to a substantial loss in N fertigated during this growing cycle, which led to the decrease in yield and, consequently, to IWP under SDI compared to SPI.

3. Large dripline spacing affected grain yield negatively at both stations

Although lateral spacing of 150 cm is generally recommended for SDI systems for maize **(e.g. Lamm et al., 2011)**, the 2012-2013 experimental results showed that lateral spacing of this range implies high risk of grain yield loss in the Mediterranean climatic conditions (yield loss from 0.4 to 1.3 t ha^{-1} at Lavalette station) but also in Oceanic transit climatic context (yield loss of 1.1 t ha^{-1} in 2013 at La Mirandette station using fertigation). Such difference in the performance is rather due to the differences in rainfall regimes were, in our context, rainfall is both lower in quantity and occurs mostly early during the growing season compared to that of other reference landmark studies on SDI such as that of **Lamm et al. (1997)** (see also **Howell et al., 1997** and **Grabow et al., 2011**).

Our results are in agreement with other observations made in the Mediterranean region (e.g. **Ben Nouna et al., 2000; Oktem et al., 2003**) were a substantial reduction has been observed up to 45% with a water deficit of 30% even for narrow drip spacing of 70 cm as reported by **Oktem et al. (2003)**. However, other experiments show that although the loss in GY exists, it is rather not significant **(Couto et al., 2013)**. However, in either case IWP was improved using SDI under the Mediterranean conditions, in line with most observations (e.g. **Oktem et al., 2003; di Paulo & Rinaldi, 2008; Couto et al., 2013**). Moreover, the lower benefit in IWP under SDI at the more humid region of La Mirandette seem in agreement with recent experiments conducted by **Vories (2009)** under temperate humid conditions were the benefit of SDI to improve maize production and productivity is questionable.

4. Conclusions and perspectives

Under Mediterranean and temperate Oceanic climatic conditions, subsurface drip irrigation system (SDI) used by applying an irrigation deficit strategy, allowed to maintain maize grain yield at high level and to lightly improve irrigation water productivity compared to the more conventional technique of sprinkler. Nevertheless, yield losses due to the irrigation water strategy under SDI technique are more significant in Mediterranean than in the temperate Oceanic region owing to the drier climatic conditions.

“Narrow” dripline spacing of 100-120 cm is preferred over “large” one of 150-160 cm under both climatic regions but more especially for Mediterranean region due also to the drier climatic conditions.

Under the temperate Oceanic climate with rainy conditions and for loam sandy clay soils, fertigation may not be a suitable method when large SDI spacing is adopted (150 cm). Under these conditions, N availability is reduced at mid-distance between two driplines. Further research is needed on both climatic regions to identify the trade-off between surface and subsurface application of N-fertilizer.

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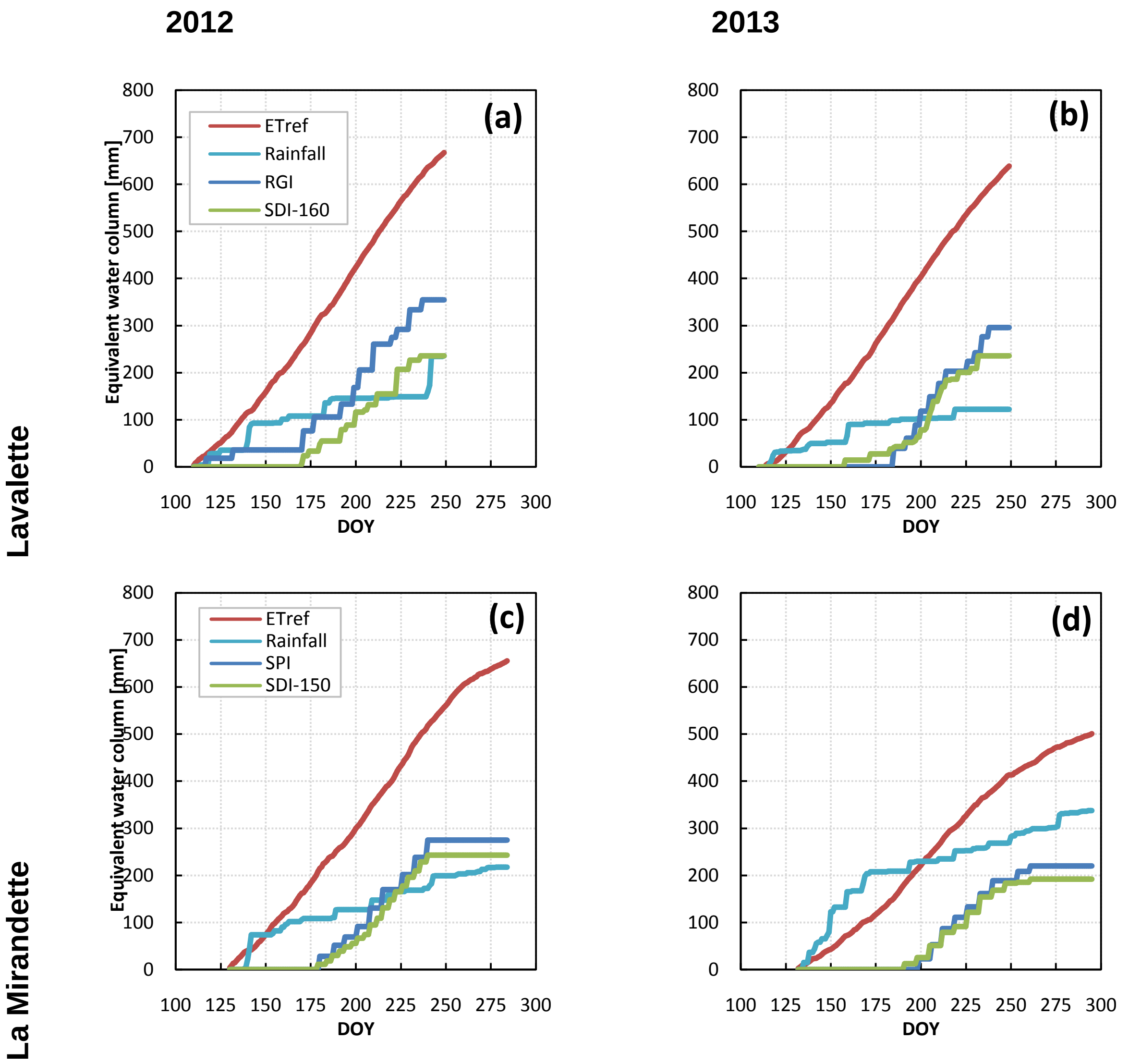
Appendix

A.1. *Cumulative rainfall, reference evapotranspiration (ETref) and irrigation during the maize growing seasons 2012 and 2013 at Lavalette (a and b) and La Mirandette (c and d).*



A.2. Agronomic practices and measurements

Agronomic practices

The Pionner PR35Y65 and P0222 corn varieties were used, respectively, in Lavalette and La Mirandette site. Both varieties are hybrid of high grain yield potential (15-16 tons of DM ha^{-1}). Prior to sowing, plots were ploughed then the preplant fertilizer was applied: 400 kg.ha^{-1} of super phosphate (45%) at Lavalette site and 350 kg.ha^{-1} of combined P-K (20%) at La Mirandette trial. Harrow passes were then performed to achieve soil surface levelling and weeds destruction. Corn was sown at a density of 80.000 seed ha^{-1} during the second half of April at Lavalette and during the first half of May at La Mirandette site. For both experimental treatments, insecticide products and starter fertilizers (30-40 kg N.ha^{-1}) were applied beneath the sowing line.

Nitrogen fertilization amounts that have been applied on experimental trials vary from 220 to 250 kg N ha^{-1} according to N content in the soil at the sowing date and the expected corn production of treatment ; Nitrogen being considered for no-limiting factor. For all spray irrigation treatments, nitrogen application took place at the beginning of each growing season, by surface application (granular form) in Lavalette RGI plot and by sub surface application (liquid form) in La Mirandette SPI field. For SDI treatments, N fertilizer was exclusively applied by fertigation (6 applications) in Lavalette plots during the two growing seasons. For La Mirandette SDI plots, in 2012 nitrogen fertilizer was applied once by sub surface application in early May whereas in 2013 it was applied first by sub surface in early June (60 kg $N.ha^{-1}$,) then by fertigation in three applications (130 kg $N.ha^{-1}$) throughout the July month.

Measurements

Soil moisture

For both experimental trials soil moisture was monitored through the volumetric water content (θ) and the water potential (ψ).

The θ was measured in order to estimate soil water-reserve in the roots zone (SWR). Measures were performed once a week using a neutron probe (CPN 503 DR, Campbell Pacific Nuclear Corp., Concord, CA, USA). Probe access tubes were installed in each plot and θ measurements were performed to a maximum depth ranging from 1.40 to 1.80 m, with a 0.1 m depth intervals. In RGI and RF treatments, only one access tube per plot was installed at a crop line. However, due to the inherent heterogeneity of water application by SDI systems, two tubes per plot were installed in SDI-160 and SDI-120 treatments in Lavalette and only in SDI-150 in La Mirandette site; the first tube being installed at a crop line and the second at equidistance between two crop/drip lines.

The ψ was measured in order to evaluate crop water-stress status as well as to estimate drainage under root zone. Corn plants are commonly considered under stress when h drops below -60 kPa soil water potential. In Lavalette site, Mercury scale tensiometer series (SDEC, France) were installed at depths from 0.1 to 1.5 m at a crop line in each treatment and data were manually collected every morning between 8:30 am and 9:30 am to avoid temperature disturbance on mercury reservoirs. In La Mirandette site, Watermark digital tensiometer probes were setup only at 30 and 60 cm of depth. Data were automatically stored in data logger and corn irrigation were triggered when tension values decreased beyond 80 kPa.

Plant growth

The monitoring of maize development was performed via the leaf area index (LAI) using a Li-Cor-2000 plant canopy analyzer device. The monitoring was performed on 5 subplots of 3 m² randomly located and georeferenced within each treatment. Subplots were delimited just after the last field mechanical work and several LAI measurements were performed throughout the main vegetative phases of corn. For both experimental sites and both growing seasons, maximum LAI was recorded at the flowering stage whatever the irrigation level (85 or 100% of crop water requirement) and the irrigation systems considered (RGI, SPI or SDI). At least, LAI measurements permit to estimate the synthetic activity rate by PILOTE.

Yield and dry matter

To determine the total dry matter production (TDM) and its partitioning into different plant components (grain, leaves, stems, etc.), corn plants were hand-harvested from 3 adjacent centre rows of the 5 subplots where LAI was monitored and, for one of them, the soil moisture. Plants were cut at ground level and ears were separated from stovers. Plants of each hand-harvested area were weighted before and after their drying into an oven at 70°C until they reached a constant mass (6-7 days) corresponding to TDM at 0% water-content. Ears were shelled by hand and grain and cob were weighted. The grain yield (GY) was then estimated as the weight of grains per unit surface at a standard water-content value of 15%. Harvest index (HI) was also calculated as the ratio of grain to biomass production on a dry basis. TDM, GY and HI for each treatment were calculated as the mean of all sub-plots corresponding values.