Response of a two-year sugar beet-sweet sorghum rotation to an agronomic management approach diversified by soil tillage and nitrogen fertilisation

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Abstract

Conservative agriculture and nitrogen fertilisation have been evaluated for the purpose of assessing their impact on the sustainability of a cropping system based on a two-year rotation with two crops considered for the bio-ethanol supply chain: sugar beet (*Beta vulgaris* L. subsp. vulgaris) and sweet sorghum (*Sorghum bicolor* L. Moench). The experimental activity started in 2009 in Foggia (Apulia, southern Italy). We discuss the results obtained in the 2010-2011 period. Soil minimum tillage (MT) *vs* no tillage (NT) combined with two doses of nitrogen fertilisation (75 and 150 kg ha^{-1} of mineral nitrogen as ammonium nitrate) were compared. The experimental system, which is still operational (soil tillage plus nitrogen fertilisation), was arranged with a split-plot design with three replicates. Treatments were applied on the same plots every year with both crops present at the same time. At the first harvest in 2010, no difference was observed. As to the second year, the comparison between NT *vs* MT treatments showed that sugar beet had lower total yield (35 *vs* 42 t ha^{-1}), dry biomass (10 *vs* 14 t ha^{-1}), and sucrose yield (6.7 *vs* 8.2 t ha^{-1}). Total soluble solids, on average 19%, were not influenced by the experimental treatments. Nitrogen (N) control was less productive than the fertilised treatments (average between N75 and N150) in terms of total fresh root yield (32 *vs* 42 t ha^{-1}), dry biomass (10 *vs* 14 t ha^{-1}), and sucrose yield (6.0 *vs* 8.1 t ha^{-1}). As with sugar beet, during the second year, also sweet sorghum sown in NT *vs* MT plots had a reduced yield, although the difference was more marked for fresh biomass (–35%) than for dry biomass (–20%). No interaction in terms of soil tillage nitrogen fertilisation occurred.

In summary, in the first two-year period (2010-2011) of the experimental trial, no tillage soil management showed decreased yields of both crops. Sugar beet displayed a higher sensitivity to the lack of nitrogen supply than sweet sorghum.

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Key words: bio-ethanol chain, biomass crops, conservation tillage.

Conference presentation: SIA XLII Congress, Reggio Calabria, 2013.

Acknowledgements: this research was carried out within the framework of the National Research Project named *Optimization of existing bioenergy chains for economic and environmental sustainability* (*Ottimizzazione delle filiere bio-energetiche esistenti per una sostenibilità economica e ambientale*) (BIOSEA, D.M. 16916/7303/10, 23 July 2010).

Funding: Ministry of Agriculture, Food and Forestry Policies (MiPAAF), Italy. Coordinator: Prof. Gianpietro Venturi, *Alma Mater Studiorum*, Bologna University.

Received for publication: 4 December 2013.
Revision received: 7 April 2014.
Accepted for publication: 19 April 2014.

Italian Journal of Agronomy 2014; 9:568
doi:10.4081/ija.2014.568

Introduction

Most areas of the Mediterranean basin are characterised by a negative water balance, a short and irregular rainy season, extreme temperatures in the summer, loss of organic matter, poor structuring of the soil, high salinity. These areas are often exposed to water and/or wind erosion, and desertification processes (Kassam *et al*., 2012).

Some agricultural practices, mainly soil tillage and crop residue management, can exacerbate these conditions, therefore agronomic research suggests adopting techniques like no tillage and/or minimum tillage, which do not disturb the soil and retain or improve its chemical and physical properties.

The adoption of conservation agricultural practices favours a balanced distribution of fertilisers, meets crop nutrient requirements, and offers an efficient management of irrigation water (Kassam *et al*., 2012; Scopel *et al*., 2013). Among the soil management systems, reduced soil tillage can contribute to the reduction of erosion, the maintenance and/or improvement of soil fertility as well as the increase of biodiversity. The minimum tillage and/or no tillage systems are well-proven for the production of cereals, however they can have a negative impact on weeded crops, like sugar beet, when shallow and non-inversion farming techniques are adopted (Koch *et al*., 2009). Other long-term benefits of conservative soil tillage consist in the improvement of the soil structure and the water infiltration, but also an increase in the cation exchange capacity, in comparison with conventionally tilled systems (Wight *et al*., 2012). In this study, two types of agronomic management techniques were compared in relation to soil tillage and mineral nitrogen fertilisation, in order to assess their impact on the sustainability of a cropping system based on a two-year rotation of two crops considered for the bio-ethanol supply chain: sugar beet (*Beta vulgaris* L. subsp. vulgaris) and sweet sorghum (*Sorghum bicolor* L. Moench).

Between 1975 and 2005, sugar beet was among the most interesting crops in the cropping systems of Southern Italy. It was considered as the classical weeded crop that opened the rotation with cereals (*i.e.* durum wheat) and vegetables (*i.e.* processing tomato). For a long time, this crop was successful as a result of the following factors: i) the autumn seeding which allowed to exploit the rain of the autumn-winter season; ii) the water deficit irrigation management during the following spring-summer season; iii) the availability of cultivated varieties suitable to specific soil and climate conditions, and resistant to bolting, also if sown in autumn; iv) the harvest in early or mid-summer, which ensured the best management of soil tillage for the following crop in the crop sequence (Cavazza, 1983; Venturi, 1988; Rinaldi, 2012).

Once the crop disappeared from the cropping systems of Southern Italy, in particular in Apulia, as a consequence of the new European Community agricultural policy, the know-how associated with it remained in any case unchanged in local farms. This could be considered a pre-condition for the reintroduction of sugar beet as an energy crop in the rotated cropping systems either for multiple purposes or strictly for the bio-ethanol supply chain (Venturi and Venturi, 2003).

Sweet sorghum is the other crop considered in the two-year rotation under study, since it produces a highly appreciated raw material as an alternative source for ethanol production (Audilakshmi *et al*., 2010). Fast growth rate and early harvesting season, great adaptability to poor soils, high water and nutrient use efficiency are among its pluses that make this crop so suitable to several agricultural areas in the Mediterranean basin (Curt *et al*., 1995; Mastrorilli *et al*., 1995, 1999; Habyarimana *et al.*, 2004; Barbanti *et al.*, 2006; Garofalo *et al.*, 2011).

This work aims to demonstrate how these crops, managed with low external inputs over a medium-term period, can both respond with an affordable yield and safeguard the agro-ecosystem, avoiding wastes of fertilisers, water, and energy.

Materials and methods

The experimental activity was performed from 2009 to 2011 in Foggia, Podere 124 farm, of the CRA–SCA (lat. 41° 8' N, long. 15° 83' E, alt. 90 m asl). The site was classified as a Typic Calcixeret (Soil Survey Staff, 2010). In the first 0.5 m-deep layer, mainly containing the roots of the considered crops, the soil is silty-clayey (sand=13.0%, silt=43.6%, clay=43.4%) and is characterised by: pH=8.3, total organic carbon (C)=35.7 g kg^{-1}, total nitrogen (N)=1.2 g kg^{-1}, C/N=10. As to its hydrological characteristics, the field capacity water content and the permanent wilting point water content are 0.396 m^3 m^{-3} and 0.195 m^3 m^{-3}, respectively. The readily available soil water content is 45% of the total soil water content. The climate is *accentuated thermo-Mediterranean* (UNESCO-FAO, 1963). Temperature can drop below 0°C in the winter and can exceed 40°C in the summer, while yearly long-term class A pan evaporation is 1604 mm (1033 mm during the sugar beet cycle, 657 mm for sorghum). Rain (yearly average=549 mm in the 1952-2008 period) is unevenly distributed and mostly concentrated between October and January (on average, 233 mm).

A two-year sugar beet-sweet sorghum rotation was considered. Two treatments, namely soil tillage and nitrogen fertilisation, were arranged in a factorial split-plot design with three replicates. The treatments were applied on the same plots, in such a way that both crops were present every year by rotating them. The main treatment was related to the type of soil tillage management, while the secondary treatment consisted in the fertilisation process with two doses of mineral nitrogen.

Minimum tillage (MT) was compared with no tillage (NT) combined with direct sowing. In particular, the MT treatment was performed by chopping the residues of the previous crop (durum wheat) in 2009, in mid-November. Residue chopping was followed by weed control (glyphosate, 5 L ha^{-1}), shallow ploughing (20-25 cm) with a five-furrow plow, phosphate fertilisation (100 kg ha^{-1} of P_2O_5), and seed bed preparation. Ploughing and seed bed preparation were not foreseen in the NT treatment.

Mineral nitrogen fertilisation was applied with 75 (N75) and 150 (N150) kg ha^{-1} of nitrogen in the form of ammonium nitrate (34%) and was compared with an unfertilised area (N0).

In the MT treatment area, seeding was performed with a precision driller, whereas in the NT treatment area a Gaspardo No-Till 1040 driller was used to sow the seeds at a depth <0.05 m, after light and shallow tillage in the strip area affected by the furrowers.

The main plot (soil tillage) and sub-plots (nitrogen fertilisation) were 24×74 m and 7×12 m, respectively.

The rotated crops were sugar beet (cv Autave) and sweet sorghum (cv Sucro 506) with field densities at harvesting of 10 and 20 plants m^{-2} respectively.

Irrigation of both crops was applied according to a deficit irrigation scheduling for sugar beet (50% of irrigation requirement) and full irrigation for sorghum (100%). The crop irrigation requirement was estimated using the soil water content measurements in the 0-80 cm depth (gravimetric method), then the amount of water to replace the soil field capacity for the same soil depth was calculated. In order to ensure uniform water distribution, a drip irrigation system was used with one line for each plant row and drippers with a 4 L h^{-1} flow.

Sugar beet was sown on 24th November 2009 and 2nd December 2010 respectively in the first and second year of the trial. Mineral N fertilisation was applied at the beginning and in the middle of May, respectively in 2010 and 2011. During the crop cycles, two and four irrigations were performed for total water volumes of 900 and 1100 m^3 ha^{-1} respectively in the first and the second year of the trial. Harvest was on 21st July 2010 and 9th August 2011.

Sweet sorghum was sown on May 7th in both years of the trial. Nitrogen fertilisation was applied on 5th July 2010 and 23rd June 2011. During the crop cycles three and seven irrigations were applied, for total water volumes of 1230 and 2120 m^3 ha^{-1} respectively in the first and second year of the trial. Harvest took place at the heading stage on 12th August 2010 and 5th September 2011.

The following parameters were determined: i) for sugar beet, the weight of total fresh and dry biomass (roots and leaves); ii) for sweet sorghum, the weight of fresh and dry biomass (leaves, stems, and panicle). The harvest sampling areas were 36 m^2 and 12 m^2 respectively for sugar beet and sweet sorghum. The dry weight was obtained by drying the vegetable samples in a ventilated oven at 70°C, until a constant weight was reached. For both crops total soluble solids (TSS) content in °Brix was measured by PR model 32 ATAGO Palette digital refractometer. For sugar beet, the theoretical sucrose yield (t ha^{-1}) was calculated by multiplying fresh root yield and TSS. For sweet sorghum, total solids (TS, %) were derived from the ratio between dry and fresh biomass weights.

The irrigation water use efficiency (IWUE, kg m^{-3}) and the nitrogen use efficiency (NUE, kg kg^{-1}) were calculated by using the ratio between the yield (fresh root biomass and sucrose yield for sugar beet; plant fresh and dry biomass yield for sorghum) and the irrigation water supplied (IWUE) and the nitrogen applied (NUE), respectively.

The data were analysed by using the statistical analysis software SAS/STAT® (SAS Institute Inc., Cary, NC, USA). The analysis of variance was performed taking into account the adopted experimental design separately for each year. Mean separation was made with the least significant difference test at a significance level of $P \leq 0.05$.

Results

Climate

In the two cropping seasons, from sugar beet sowing to sorghum harvesting, minimum temperature (Tmin), maximum temperature (Tmax), and monthly cumulative rainfall followed the climatic long-term trend of the experimental site (1952-2008) (Figure 1).

During the winter, the monthly Tmin fluctuated between 3-4°C (2010) and 2-4°C (2011), while, during the summer, in particular in the months of July and August, the monthly Tmax was around 34°C. As to rainfalls, the cumulative value of the 2009-2010 cropping season was +17% compared with the corresponding value for the long-term period (525 *vs* 450 mm), while, in the 2010-2011 cropping season, it was closer to the value for the long term period (495 *vs* 496 mm). In both cases, rainfalls were concentrated between October and April. Some exceptions need to be underlined for the purposes of this study. In the 2010-2011 growing season, Tmin was lower than 2.2°C, and Tmax was higher than 2.4°C *vs* the corresponding values of the long-term period, respectively in December 2010 and August 2011. In May 2011, the rainfall value was 101 mm (39 mm in the long period). In 2010 and 2011, August was characterised by a complete absence of rainfall which, together with very high temperature peaks (the so-called heat waves), could have influenced the final stage of the crop cycles of both sugar beet and sweet sorghum.

Crops

The statistical analysis of crop production variables did not show any significant variation in the first year, neither in terms of main effects nor of interaction, except for NUE for both crops. In the second year, several production variables and resource efficiency indices showed significant variations in terms of main effects.

Sugar beet

First year: 2009-2010 (Table 1). As was said before, no difference was reported between the experimental treatments in the first year. On average, fresh root yield was 41.2 t ha^{-1}. However, roots at harvest were characterised by a high content of TSS, 19.4 °Brix on average, which gave a theoretical sucrose yield of 8 t ha^{-1} on average. This value is considered the cost-effectiveness threshold for sugar beet in Southern Italy.

No statistical differences were observed in terms of both soil

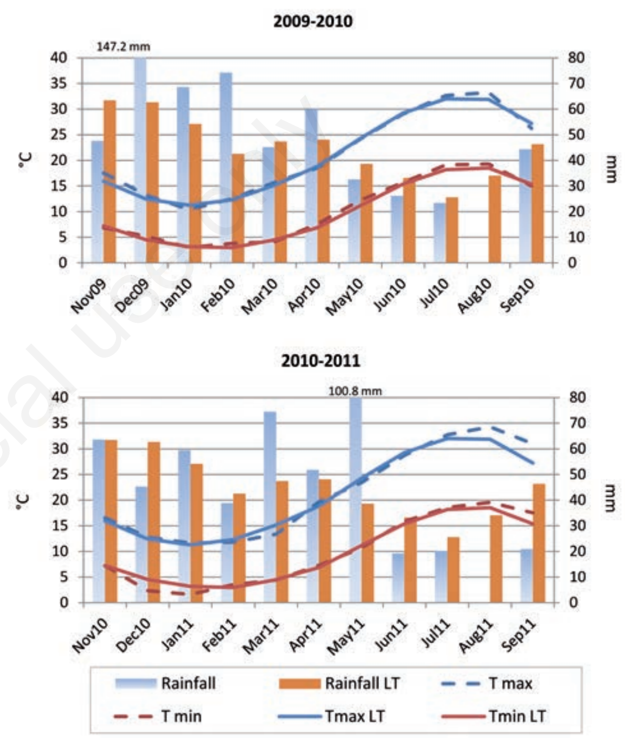

Figure 1. Climate description of the two cropping seasons (2009-2010 and 2010-2011) compared to long-term data (Foggia, 1952-2008).

Table 1. Yield response of sugar beet, total soluble solids, irrigation water use efficiency for fresh roots yield and sucrose yield, nitrogen use efficiency for fresh root yield and sucrose yield as influenced by soil tillage and fertilisation treatments in the first year of the trial, Foggia, 2009-2010.

Treatment	Roots yield t ha^{-1}	Dry biomass t ha^{-1}	TSS °Brix	Sucrose t ha^{-1}	IWUE$_y$ kg m^{-3}	IWUE$_{suc}$ kg m^{-3}	NUE$_y$ kg kg^{-1}	NUE$_{suc}$ kg kg^{-1}
MT	40.1	13.7	19.1	7.7	44.5	8.6	412.0	79.4
NT	42.4	14.2	19.6	8.3	47.1	9.2	432.1	84.0
N0	38.9	12.7	19.4	7.6	43.2	8.4	-	-
N75	41.9	14.1	19.2	8.1	46.6	9.0	558.9^a	107.5^a
N150	42.8	15.1	19.6	8.4	47.5	9.3	285.2^b	55.8^b
2009-2010	41.2	14.0	19.4	8.0	45.8	8.9	422.1	81.6

TSS, total soluble solids; IWUE$_y$, irrigation water use efficiency for fresh roots yield; IWUE$_{suc}$, irrigation water use efficiency for sucrose yield; NUE$_y$, nitrogen use efficiency for fresh root yield; NUE$_{suc}$, nitrogen use efficiency for sucrose yield; MT, minimum tillage; NT, no tillage; N, nitrogen. ^{a,b}Values followed by different letters within columns are significantly different (Fisher's least significant difference test, $P \leq 0.05$).

tillage management and fertilisation doses. No difference was seen in IWUE for fresh roots and sucrose between the different types of soil tillage management. They were 47.1 and 9.2 kg m^{-3}, and 44.5 and 8.6 kg m^{-3}, for the NT and the MT treatments respectively. The rising doses of nitrogen slightly increased IWUE. By doubling doses of nitrogen, its use efficiency (NUE) halved. For each kg of applied N, 559 *vs* 285 kg of fresh roots and 108 *vs* 56 kg of sucrose were derived respectively for N75 and N150 treatments.

Second year: 2010-2011 (Table 2). MT confirmed the production levels which were achieved previously in terms of fresh roots, dry biomass, TSS and sucrose yield. In contrast, sugar beet grown on NT soil for the second consecutive year evidenced a significant decrease of fresh roots and dry biomass (–18% and –24%, respectively), and sucrose yield (–18%), whereas TSS valve was similar to the NT treatment. As to nitrogen fertilisation, the results obtained with N75 and N150 treatments were similar. The unfertilised test area was found to be less productive than in the previous year, thus highlighting the sensitivity of sugar beet to the depletion of nitrogen in the soil, if external inputs are inadequate. As to NT and N0, the yield response of the crop was very low (26 t ha^{-1} of fresh root yield and 5 t ha^{-1} of sucrose yield; data not show). Contrary to what was observed in the first year, the IWUE was higher in the MT treatment (38.4 and 7.4 kg m^{-3} respectively for the fresh roots and the sucrose yield) than in NT treatment (31.4 and 6.1 kg m^{-3}).

The effect of nitrogen was similar in N75 and N150 treatments which, anyway, exceeded by more than 30% the unfertilised test area (N0). This highlights that there is close link between water and nitrogen availability and therefore an effect on the photosynthetic response and the final productivity of sugar beet. The nitrogen use efficiency was higher in MT than NT (on average, +15%). Like in the previous year, NUE was halved both for fresh roots and sucrose yields, when the dose of mineral fertiliser was doubled.

No significant effect of the interaction of soil tillage x nitrogen fertilisation emerged from the examined variables.

Sweet sorghum

First year: 2010 (Table 3). There were no significant differences between MT and NT treatments with regard to fresh and dry biomass and TSS. N150 treatment produced a very limited increase of dry biomass (about +2%) compared with N0 and N75 (on average, 26.2 t ha^{-1}), while it increased TSS content by 8%.

The IWUE for dry biomass was 21.3 and 19.6 kg m^{-3} respectively in MT and NT treatments. The application of 150 kg ha^{-1} of nitrogen promoted a slight increase of IWUE with respect to dry biomass (+8%) and TSS (+14%).

As to the dry biomass and sucrose content, the NUE values decreased by 95% and 61%, respectively, when the doses of mineral nitrogen fertiliser were doubled.

Second year: 2011 (Table 4). Though the differences between the first and the second year were evident for fresh biomass (average decrease by about 35%), on the other end dry biomass was reduced by 20%. In fact, the plants showed at harvest higher values of TSS and TS with positive consequences from a qualitative point of view. This could also be due to a severe water stress as a consequence of the dryness

Table 2. Yield responses of sugar beet, total soluble solids, irrigation water use efficiency for fresh roots yield and sucrose yield, nitrogen use efficiency for fresh root yield and sucrose yield as influenced by soil tillage and fertilisation treatments in the second year of the trial, Foggia, 2010-2011.

Treatment	Roots yield t ha^{-1}	Dry biomass t ha^{-1}	TSS °Brix	Sucrose t ha^{-1}	IWUE$_y$ kg m^{-3}	IWUE$_{suc}$ kg m^{-3}	NUE$_y$ kg kg^{-1}	NUE$_{suc}$ kg kg^{-1}
MT	42.3^a	13.7^a	19.3	8.2^a	38.4^a	7.4^a	445.7^a	87.6^a
NT	34.6^b	10.4^b	19.3	6.7^b	31.4^b	6.1^b	390.1^b	75.6^b
N0	31.6^b	9.6^b	19.0	6.0^b	28.7^b	5.5^b	-	-
N75	41.7^a	13.6^{ab}	19.7	8.2^a	37.9^a	7.5^a	555.6^a	109.7^a
N150	42.0^a	14.1^a	19.2	8.0^a	38.2^a	7.3^a	280.2^b	53.5^b
2010-2011	38.4	12.4	19.3	7.4	34.9	6.8	417.9	81.6

TSS, total soluble solids; IWUE$_y$, irrigation water use efficiency for fresh roots yield; IWUE$_{suc}$, irrigation water use efficiency for sucrose yield; NUE$_y$, nitrogen use efficiency for fresh root yield; NUE$_{suc}$, nitrogen use efficiency for sucrose yield; MT, minimum tillage; NT, no tillage; N, nitrogen. [a,b]Values followed by different letters within columns are significantly different (Fisher's least significant difference test, P≤0.05).

Table 3. Yield response of sweet sorghum, total soluble solids, total solids, irrigation water use efficiency for fresh biomass yield and dry biomass yield, nitrogen use efficiency for fresh biomass yield and dry biomass yield as influenced by soil tillage and fertilisation treatments in the first year of the trial, Foggia, 2010.

Treatment	Fresh biomass t ha^{-1}	Dry biomass t ha^{-1}	TSS °Brix	TS %	IWUE$_y$ kg m^{-3}	IWUE$_{dm}$ kg m^{-3}	NUE$_y$ kg kg^{-1}	NUE$_{dm}$ kg kg^{-1}
MT	114.9	27.5	9.0	23.9	89.1	21.3	1532.0	366.7
NT	110.3	25.3	8.5	23.0	85.5	19.6	1470.7	337.3
N0	111.5	26.3	8.5	23.6	86.4	20.4	-	-
N75	109.4	26.2	8.4	23.9	84.8	20.3	1458.7^a	349.3^a
N150	116.8	26.7	9.2	22.9	90.5	20.7	778.7^b	178.0^b
2010	112.6	26.4	8.7	23.5	87.2	20.5	1123.7	263.6

TSS, total soluble solids; TS, total solids; IWUE$_y$, irrigation water use efficiency for fresh biomass yield; IWUE$_{dm}$, irrigation water use efficiency for dry biomass yield; NUE$_y$, nitrogen use efficiency for fresh biomass yield; NUE$_{dm}$, nitrogen use efficiency for dry biomass yield; MT, minimum tillage; NT, no tillage; N, nitrogen. [a,b]Values followed by different letters within columns are significantly different (Fisher's least significant difference test, P≤0.05).

Table 4. Yield response of sweet sorghum, total soluble solids, total solids irrigation water use efficiency for fresh biomass yield and dry biomass yield, nitrogen use efficiency for fresh biomass yield and dry biomass yield as influenced by soil tillage and fertilisation treatments in the second year of the trial, Foggia, 2011.

Treatment	Fresh biomass t ha^{-1}	Dry biomass t ha^{-1}	TSS °Brix	TS %	IWUE$_y$ kg m^{-3}	IWUE$_{dm}$ kg m^{-3}	NUE$_y$ kg kg^{-1}	NUE$_{dm}$ kg kg^{-1}
MT	78.1^a	22.1	13.1^b	28.4	69.7^a	19.7^a	1041.3^a	294.7^a
NT	63.8^b	19.7	14.7^a	30.7	57.0^b	17.6^b	850.7^b	262.7^b
N0	67.8	19.3	13.5	30.5	60.5	17.2	-	-
N75	69.0	20.9	14.3	28.2	61.6	18.7	920.0^a	278.7^a
N150	76.0	22.5	13.9	30.0	67.9	20.1	506.7^b	150.0^b
2010-2011	70.9	20.9	13.9	29.6	63.3	18.7	713.3	218.8

TSS, total soluble solids; TS, total solids; IWUE$_y$, irrigation water use efficiency for fresh biomass yield; IWUE$_{dm}$, irrigation water use efficiency for dry biomass yield; NUE$_y$, nitrogen use efficiency for fresh biomass yield; NUE$_{dm}$, nitrogen use efficiency for dry biomass yield; MT, minimum tillage; NT, no tillage; N, nitrogen. ^{a,b}Values followed by different letters within columns are significantly different (Fisher's least significant difference test, P≤0.05).

occurred in August 2011, just partially offset by deficit irrigation.

As was observed for sugar beet, in this second year, a yield reduction was reported with NT *vs* MT (–18%), although the difference was significant for fresh, but not for dry biomass yield. In contrast, NT was more efficient than MT in relation to TSS.

Between the two types of soil tillage management, soil water content did not differ consistently, either at the time of sowing and at harvest (data not shown). The yield response to applied nitrogen doses was not significantly different.

The calculated IWUE values of dry and fresh biomass yields were significantly higher with MT (19.7 kg m^{-3}) compared with NT (17.6 kg m^{-3}). The NUE doubled by halving the dose of nitrogen, thus confirming the results obtained in the first year. With regard to the interaction of soil tillage and nitrogen fertilisation, no significant difference emerged in the examined production parameters.

Discussion

Despite the short time of the experiment, some useful indications have emerged.

Sweet sorghum gave a high fresh and dry biomass yield in both years, also with a deficit irrigation scheduling. It also proved to have a great potential under the climatic and soil management conditions reported above. High dry biomass accumulation (26 t ha^{-1}) with small amounts of water applied (114 mm) was also underlined by Curt *et al*. (1995) about sweet sorghum grown in Spain. These productivity levels are comparable with those of biomass sorghum (Habyarimana *et al.*, 2004) with a dry biomass accumulation (from 20 to 29 t ha^{-1}) close to our experimental values under similar environmental and rainfall conditions. However different results were reported by Berenguer *et al*. (2001) with water irrigation volumes similar to those of our experiment (on average 168 mm). He observed a dry biomass accumulation equal to 11.5 t ha^{-1}, which is almost half if compared with the sorghum biomass observed.

The sorghum IWUE$_{dm}$ was very high, if compared to the values reported in literature and mainly to the results from sugar beet in this experiment. As shown by the field results, the efficiency of sweet sorghum in converting water into biomass was very high also when small amounts of water were applied, even if in the literature there are reports (Farrè and Faci, 2006) with values of IWUE$_{dm}$, between 2.89 and 3.75 kg ha^{-1}, when shifting from optimal to stressed water conditions. Also in biomass sorghum, IWUE$_{dm}$ triplicated, when water applied was decreased (from 4.38 to 12.42 kg m^{-3}; Garofalo and Rinaldi, 2013), but it was heavily affected by the soil water content at sowing. Field trials and data from the literature clearly show that IWUE$_{dm}$ in sorghum grown in the Mediterranean area can vary remarkably from 5.84 to 22.81 kg m^{-3}, even with similar amounts of irrigation water applied, especially in reduced water regimes. This can be mainly explained by the amount and distribution of rainfalls, but also by the soil moisture content at sowing (Garofalo and Rinaldi, 2013).

Sugar beet gave a worse response for most measured parameters compared with sorghum. Rinaldi and Vonella (2006) reported in the same Mediterranean environment and under the same deficit irrigation conditions (on average 249 mm of irrigation and 353 mm of rainfall) values for fresh root yield ranging between 38.2 and 60 t ha^{-1} in three experimental years, which are very close to the results of our experiment obtained with 100 mm of irrigation water and 442 mm of rainfall water (average of the two seasons). In the same research (Rinaldi *et al.*, 2006) the IWUE$_y$ doubled in the wettest year (24 *vs* 15 kg m^{-3}) and the average IWUE$_{suc}$ was 3.72 kg m^{-3}.

In this study, despite the irrigation volumes were lower (less than 150 mm) than the ones reported by the same authors, IWUE$_y$ was 75% greater, probably due to a better rainfall distribution during the two growing periods (473 mm in the first and 410 mm in the second one, during sugar beet crop cycle). High variability of IWUE$_y$ as a consequence of water irrigation is confirmed also by Sepaskhah and Kamgar-Haghighi (1997) with values ranging from 19.1 to 44.4 kg m^{-3} when shifting from 2248 to 675 mm of irrigation water in two experimental years with a different rainfall pattern and very low values for IWUE$_{suc}$ (0.54 kg m^{-3}). These experimental findings highlight the importance of the initial soil water content for the final yield performance of the crop.

Sugar beet and sweet sorghum proved to have a great capacity for exploiting the water stored in the soil, thanks to their deep root systems (Vamerali *et al.*, 2003; Himmelbauer *et al.*, 2004). In the two experimental years, the water stored in the two months before sowing (on average 144 mm for sugar beet and 125 mm for sorghum), and during the growing cycles, allowed the crops not to suffer from water stress, in spite of (and thanks to) deficit irrigation. This could explain the high value of IWUE, which corresponds to high productivity with low amount of irrigation water.

Moreover, sorghum is a crop with good nitrogen use efficiency (Gardner *et al.*, 1994). For the same reason, the lack of response to nitrogen application is a common phenomenon observed in this crop. Indeed, N application had no impact on sweet sorghum growth and yield partitioning among plants organs (Barbanti *et al.*, 2006). In addition, sugar yield did not change with N application (Wortmann *et al.*, 2010). This implies that sweet sorghum can be cultivated with little N application with no negative impact on sugar content yield. A different response was observed in the sugar beet, which has a well-known sensitivity to N deficiency, that causes delays in leaf growth and canopy closure, accelerates leaf senescence, and reduces capture of solar radiation (Mildford, 1985; Draycott and Christenson, 2003).

Conclusions

No difference was identified between the experimental treatments in the first year of the discussed experimental trial in terms of neither the type of soil tillage management (minimum *vs* no tillage) nor the mineral nitrogen fertilisation. As for the results of the second year, no tillage appeared to adversely affect the growth of both examined crops, resulting in a reduced yield. Only the dry biomass of sweet sorghum was not different between the two types of soil tillage that were compared.

Sweet sorghum proved capable of exploiting the soil water content and transforming irrigation water in a very efficient way with very high yields in terms of both fresh and dry biomass. With regard to the response to mineral nitrogen fertilisation, sugar beet showed a higher sensitivity to the deficiency of external inputs, if compared with the results of sweet sorghum.

A comparative analysis of the energy balance and CO_2 air emission in the six combinations of soil tillage and nitrogen fertilisation will allow a more accurate assessment of these crop management options.

The continuation of the planned experimental trial might give more useful long-term information on the capability of sugar beet and sweet sorghum of maintaining crop yield levels under conditions of no tillage and different nitrogen supply management methods.

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