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Potential And Water-Limited Growth And Productivity Of Fiber Sorghum In Central Greece Irrigated By Surface And Subsurface Drip Methods On A Rainy And A Dry Year

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Abstract
Growth evolution and biomass yield of fiber sorghum [Sorghum bicolor (L.) Moench] variety FS-5 were studied under field conditions in central Greece in the years 2001 and 2002, using a completely randomized block design with three treatments in four replicates.(including control) The project comprised two irrigation methods: conventional drip irrigation and modern subsurface drip irrigation. Both treatments received at regular intervals the same irrigation amount for matching half of the evapotranspiration needs (supplemental irrigation) in the first year (2001), and the total evapotranspiration needs (full irrigation) in the second year (2002). Irrigation in both systems was applied in laterals placed 1.6 m apart with a distance of 0.6 m between the self-regulated emitters, recharging 3.75 $m^3 h^{-1}$. The fully automatic subsurface irrigation system was placed at a depth of 0.45 cm from the soil surface. The growth (plant height, leaf area index) and biomass productivity of the crop was measured in periodical samplings throughout the growing period in both years. The results demonstrated a great superiority of the subsurface drip method on growth and total biomass production apparently due to the minimal evaporation losses and the better water distribution in the rooting zone occurring under subsurface irrigation. The crop irrigated with this system reached yields of 38.6 and 18 t ha^{-1}, under full (in 2002) and supplemental (in 2001) irrigation, respectively. The respective yields under surface drip irrigation were significantly lower, i.e. 33.3 t ha^{-1} (in 2002) and 12 t ha^{-1} (in 2001). Moreover, the obtained results demonstrated the great potentiality of fiber sorghum as alternative commodity for biomass production in Greece, according to the focus of the sustainable, alternative agriculture under both high and low irrigation inputs.

Key-words: fiber sorghum, biomass production, bio-energy crops, modern irrigation, water conservation.

1. Introduction

Following the increasing interest for renewable raw materials included in the new course of EU agricultural policy, a particular attention was given to biomass crops in the last decade.

Sorghum, a C4 plant of tropical origin, 5th most important cereal crop, used for green fodder, thatch and silage and also produce syrup and fuel (ethanol), grown on 44 million ha especially in poor and semi-arid areas which are too dry for maize in 99 countries around the world, domesticated perhaps in Ethiopia between 5,000-7,000 years ago, performing high photosynthetic efficiency, low fertilizer requirements, big advantages when used in a crop rotation scheme, high biomass yields and dry matter accumulation rates, has received considerable attention during the last years as an alternative source for energy production. Previous research has stressed that the crop is well adapted to the warm southern EU regions and especially at diverse geographic locations throughout Greece [1, 2]. Sorghum, compared to other crops is more environment-friendly from the agronomic point of view [2], especially due to its relatively low nitrogen needs [3] and water requirements [4]., has also been called «a camel among crops», owning to its wide adaptability, its marked resistance to drought and saline–alkaline soils, and tolerance to water-logging. Considering sorghum as an alternative energy crop in the near future that requires (supplemental) irrigation under Greek conditions, the crop could be irrigated using the existing irrigation methods and

systems. The most important of these systems, used to irrigate traditional commodities in Greek lowlands, are traveling guns and drip irrigation.
Drip irrigation was common practice in many orchards and vineyards already since early 1980's, whereas only a few progressive cotton farmers applied drip irrigation by 1988 [5].Water scarcity and cost reduction resulted in a great expansion of drip irrigation in the Greek lowlands, so that most of these areas are irrigated with drip methods today.
A variation of the conventional surface drip irrigation method is the subsurface drip irrigation that is gaining place nowadays in many irrigated areas [6, 7]. According to this method, the laterals are buried in a depth below the soil surface depending mostly on crop type and tillage practices. Many advantages of this method are reported from the literature.
Firstly, since the drip system is buried, irrigation system performance is unaffected by surface infiltration characteristics. On the other hand, the upper soil has lower moisture content so that evaporation is practically eliminated. A relatively dry soil surface permits farm equipment access and movement during the whole irrigation period and eliminates weed growth; it restricts root rot and other soil diseases and prevents crust formation that inhibits soil aeration and rainfall water infiltration into the soil causing surface runoff [8].
A subsurface irrigation system is not exposed to sun and extreme weather conditions that means longer material life. Using such systems, irrigation water and injected fertilizers are delivered directly to the crop's rooting zone; this is particularly advantageous for nutrients with low mobility in the soil [9].
The permanent installation of this system below the plough layer appreciably reducing the labor costs is also very advantageous. It's obvious that will need to be found technologies that improve the plant's better access to water and nutrients.
Disadvantages of this method may be considered the high installation cost, the difficulty of inspecting and repairing the system, and the capability of the system to provide adequate moisture conditions for germination.
Based on the above, and considering fiber sorghum [Sorghum bicolor (L.) Moench] as a possible alternative crop for biomass production in Greece in the near future, the present work focuses on the growth and biomass productivity of this crop as affected by the existing drip irrigation method and by the newly introduced subsurface irrigation method, under full and supplemental irrigation schemes.

2. Materials and methods

The biomass productivity of the fiber sorghum [Sorghum bicolor (L) Moench] variety FS-5 was studied under field conditions in central Greece (experimental farm of the University of Thessaly) in 2001 and 2002 using a randomized block design with three treatments in four replicates.(including control) The treatments comprise two different irrigation methods, surface drip irrigation and subsurface drip irrigation.
The crop was sown on May 5th, 2001 and on May 28th, 2002 at distances of 0.8 m between the lines and 14.3 cm between the plants (total plant density: 8.4 plants m^{-2}).
All treatments received at regular intervals the same irrigation amount for matching in 2001 half of the evapotranspiration needs and in 2002 the total evapotranspiration needs (approximated using the Class-A pan evaporation method). Fertilization was not applied, in line with the general consideration of introducing biomass crops and particularly sorghum in low-input farming systems in central Greece.
The laterals of both the surface and subsurface drip systems were of 20 mm polyethylene pipe with in-line RAM self regulated emitters discharging at a constant low rate of 3.6 l h^{-1}. Surface and subsurface drip irrigations were applied in laterals of 1.6 m apart and 0.6 m between the emitters, thus recharging 3.75 m^3 h^{-1}.
The fully automatic subsurface irrigation system was placed at a depth of 0.45 m from the soil surface. It was additionally equipped with a vacuum breaker valve to prevent any water suction and consequently emitter clogging when irrigation pauses, and also with a disk filter enriched with triflouralin, which was injected during irrigation for preventing root intrusion. The irrigation control valves were connected to an irrigation controller (Miracle-Netafim) for making irrigation fully automated.
During the total irrigation period (18/6-9/10/2001), 12 applications depths were realized with a total water input of 260 mm. In 2002, 17 irrigations depths were applied with a total water input of 280 mm according to evapotranspiration needs. Considering the amount of rain falling during the irrigation periods of 2001 and 2002, viz. 60 mm and 300 mm, respectively (see later and Fig. 1), the total water inputs were 320 mm and 580 mm for 2001 and 2002, respectively.
The growth of the crop was measured by means of plant height and leaf area index, which were recorded in periodical samplings throughout the

growing period. The leaf area index was measured using a LAI-COR detector of Gambell Scientific.
Biomass production (above ground part) was measured in three harvests during the end of growing period, and particularly at the dates 31/8, 21/9 and 10/10/2001, and six harvest during the growing period of 2002, and particularly at the dates 15/7, 16/8, 4/9, 22/9, 8/10 and 4/11/2002. Leaf blades and stalks were harvested separately.
All samples were dried at 90°C until constant weight. Meteorological data (daily maximum and minimum air temperature, precipitation and class-A pan evaporation rates) were recorded in a fully automatic meteorological station, which was installed some 30 m from the experimental field.

3. Results and discussion

3 Weather data

The study area is characterized by a typical Mediterranean climate with hot and dry summer and cool-humid winter. Fig.1 schematically presents the air temperature and precipitation (10-day average values) prevailing at the experimental site during the growing periods of 2001 and 2002 and in an average year.
It can be seen that air temperature during the growing period of 2001 did not fluctuate much from its values on an average year.

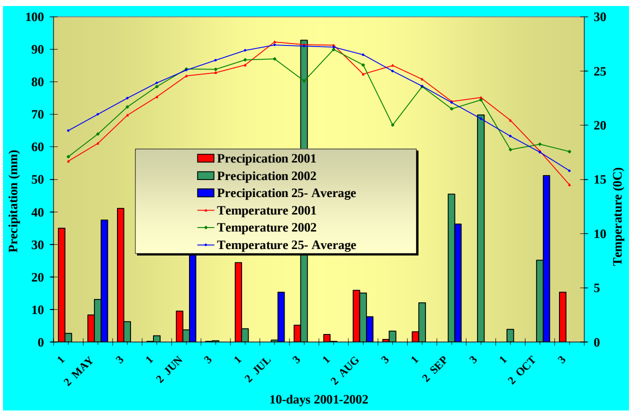

Fig.1. Temperature and precipitation (10-days mean values) occurring in the study area during the growing period of sorghum in 2001, 2002 and in an average year.

It was slightly lower than average (up to 1°C) in early summer ranging from about 20°C in mid-May to 26°C in late June. It remained constant at about 27.5°C during July and early August, and dropped to values between 24.5 and 25.5°C from mid-August to early September but remained above 20°C until the second decade of October. With the exception of a rainy May (total rainfall 84 mm), the growing period of 2001 was particularly dry with only 60 mm of rain falling in the period from the beginning of June until mid-October (Fig. 1.).
Under such conditions and more generally under the conditions in central Greece, most summer crops including sorghum need irrigation to perform acceptable yields.
On the opposite, the summer of 2002 was cooler and moister than average. As can be observed in Fig.1, precipitation was almost twice as much as in an average year (about 300 mm rain from June to September). Especially rainy were the months July and September with precipitation 98 and 127 mm, respectively.
The growing period of 2002 was also characterized by lower air temperature than in an average year, especially during the critical months of July and August, and can be considered more favorable for sorghum growth and productivity.

4 Crop growth

4.1 Plant height

Fig.2 illustrates the growth of sorghum as reflected by plant height for the two irrigation methods and control under supplemental (2001) and full (2002) irrigation inputs.
It can be observed that initially all treatments performed similar growth rates (approximately 3 cm d^{-1}) to reach a height of about 120 cm by mid-July.

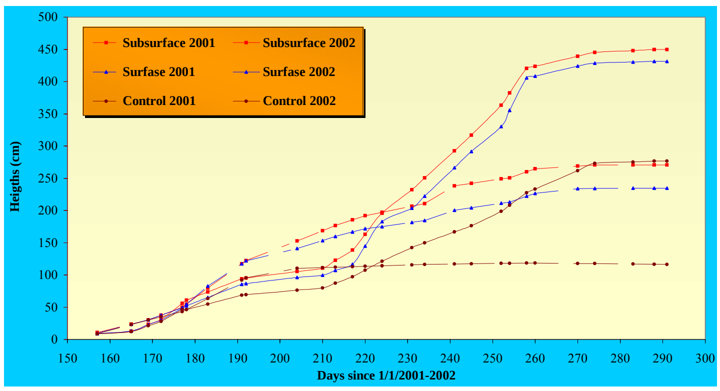

Fig.2. Plant height evolution of fiber sorghum irrigated with surface and subsurface drip irrigation systems in central Greece in 2001 under supplemental irrigation (50% ETm), and in 2002 under full irrigation (100% ETm).

This is apparently due to the initial use of the water stored in the soil before the onset of irrigation, which was equal among the various treatments. After the starting of irrigation, the fully irrigated plants in 2002 exhibited remarkable growth rates, e.g. 4.8 and 5.9 cm d^{-1} for surface and subsurface irrigation, respectively, in the period 20 July–end of August. Smaller growth rates were observed in September (3.2 and 3.6 cm d^{-1}, respectively), to reach by the end of September particularly great heights of 425 and 450 cm for surface and subsurface irrigation, respectively.

Although the difference in final height (25 cm) was not statistically significant, the differences in growth rates in the period 20/7-30/8 were statistically evident at $P<0.10$, signaling superiority of the subsurface versus the surface irrigation method. This superiority was more clear under the water limited conditions of 2001 (statistical differences at *$P<0.05$).

Actually, after mid-July, the height of the plants receiving subsurface irrigation increased with rates of about 2.2 cm d^{-1} throughout the rest of the growing period and reached a maximum value of about 270 by late September (Fig.2). The plants receiving conventional drip irrigation performed smaller growth rates (1.6 cm d^{-1}) reaching a maximum height of 235 cm by the end of September.

4.2 Leaf area index

Leaf area expansion is of great importance for light interception and for photosynthesis; it varies with the quantity of assimilates allocated to the production of leaves and the ratio of the leaf area produced per unit of leaf dry matter.

Many studies consider maximum assimilation when leaf area index (LAI) takes values above 4-5, whereas LAI-values rather lower than 3 characterize open leaf canopies and considerable loss in photosynthetically active radiation.

In the case of the fully irrigated crop (2002), the canopy was closed (LAI>6) already by mid-August, so it might be interested to focus on how long those rates of LAI were higher than value 5. So, the total time for subsurface irrigation was 85 days, 69 days for surface irrigation and only 15 days for the control. That difference gave the opportunity to the plants that were irrigated subsurface to achieve greatest productive rates against the other irrigation method.

Also, as concerns the crops that grown under supplemental irrigation and moderate water stress. Fig.3 shows that the maximum LAI value was attained by early September and was about 4.3, with the plants irrigated with subsurface method performing greater LAI values, but this superiority was not statistically evident.

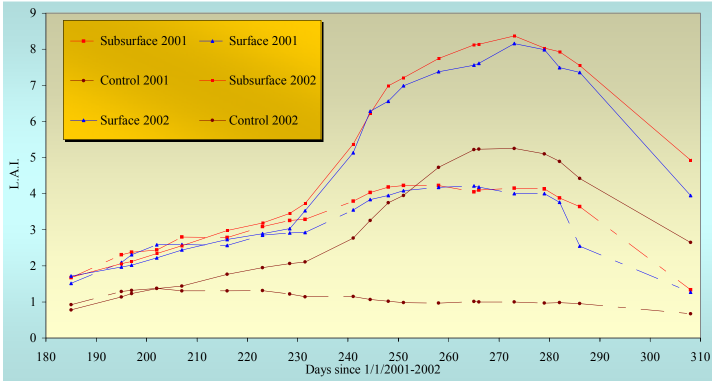

Fig.3. Leaf area index evolution of fiber sorghum irrigated with surface and subsurface drip irrigation systems in central Greece in 2001 under supplemental irrigation (50% ETm) and in 2002 under full irrigation (100% ETm).

It should be noted that unpublished results on sweet sorghum (cv. Keller) by CRES justify maximum LAI values of about 4.5 under conditions of moderate water inputs using drip irrigation and no fertilization.

It might thus be concluded that further depression in the water inputs, i.e. matching less than half of the evapotranspiration needs, would enhance the risk of an open canopy and thus an appreciably greater loss in assimilation and productivity, and should be seriously taken into consideration under the xerothermic conditions under study.

4.3 Biomass production

Fig.4 illustrates the evolution of dry biomass yield of fiber sorghum under full irrigation in 2002. It can be observed that the plants receiving subsurface irrigation exhibited considerably higher growth rates than those receiving water with the surface drip method (**$P<0.01$), demonstrating the clear superiority of the subsurface irrigation on the growth and productivity of the crop.

As discussed earlier, this must be attributed to the supply of the water directly to the rooting zone and the more effective water irrigation with respect to the minimization of the evaporation losses from the soil surface, which remains dry in the case of subsurface irrigation.

Especially during the period from 17/8 to 4/9/2002, growth rates as much as 430 kg $ha^{-1}d^{-1}$ were reached under subsurface and 350 *kg* $ha^{-1}d^{-1}$ under surface irrigation, respectively. Maximum biomass production was attained by the end of September and was 38.6 and 33.3 t ha^{-1} for subsurface and surface irrigation, respectively. Such productivity values are particularly high, and assuming that the thermal value of sorghum biomass be about, 17 MJ kg^{-1} [10], they correspond to 15.4-13.3 tons oil equivalent (TOE) per hectare as you can see in Fig.5.

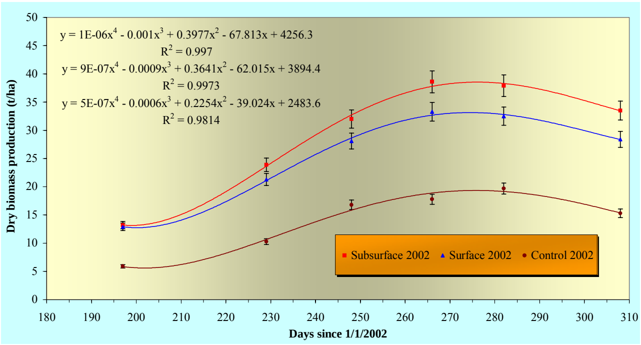

Fig.4. The evolution of the total (above ground) dry biomass of fiber sorghum under full irrigation with surface and subsurface drip methods in central Greece in 2002. [Vertical bars reflect LSD (*P<0.05)].

The superiority of the subsurface vs. surface irrigation method was also found under the water-limited conditions in 2001. As shown in Fig.6, the plants receiving subsurface irrigation attained a maximum biomass yield of 18.6 t ha^{-1} by the end of August, whereas the plants irrigated with the surface drip method reached a considerably lower production of 13.8 t ha^{-1} ($LSD_{0.05}$=4.54 t ha^{-1}).

It should be noted here that a neighboring non-irrigated fiber sorghum plantation reached 5.1 t ha^{-1} in dry biomass, which, is not negligible production considering the prolonged drought occurring during the growing period of 2001.

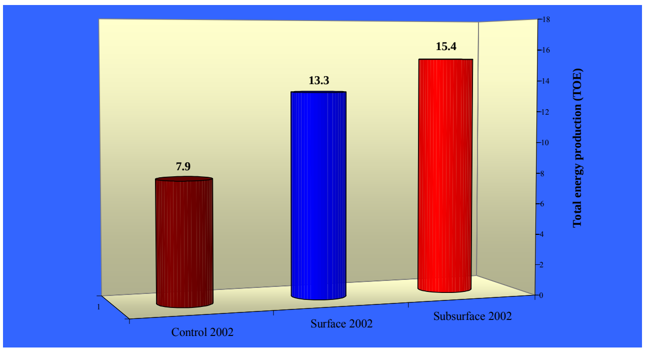

Fig.5. Total energy production (TOE) of fiber sorghum irrigated with surface and subsurface drip irrigation systems in central Greece in 2002 under full irrigation (100% ETm).

This modern irrigation method seems to be very promising and should be considered seriously in future feasibility studies of farming systems with low inputs such as those including the bio-energy crops.

Considering the attained maximum yield of fiber sorghum both under full (>38 t ha^{-1}) and supplemental irrigation (18 t ha^{-1}) roughly corresponding to 15 and 7.2 Tons Oil Equivalent (TOE) under full and supplemental irrigation and non-fertilization inputs, this crop seems very promising alternative commodity for biomass production in Greece in the near future.

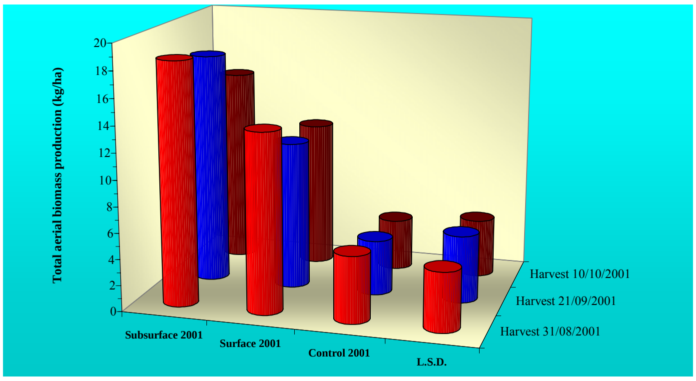

Fig.6. Total (above ground) dry biomass production of supplementary irrigated (50% ETm) fiber sorghum with surface and subsurface drip methods in central Greece in 2001. (LSD at level *P<0.05).

During the last three weeks of September, water-limited biomass production decreased with appreciable rates especially under surface drip irrigation. Considerable yield loss was also observed in the crop receiving subsurface drip irrigation but somewhat later, i.e. in the period mid-September to mid-October (negative rates of 120 kg ha^{-1} d^{-1}). It can be seen that the final yield dropped to 15.1 t ha^{-1} e.g. about 3.4 t ha^{-1} lower than its peak attained one month earlier.

Such negative growth rates and considerable yield decreases at late crop growth stages were reported from previous studies on sweet sorghum cv. Keller (CRES, unpublished data) and were attributed to leaf senescence as well as the increased respiration losses which could not be matched by crop assimilation late in the season. Obviously, the time that maximum yield of sorghum is attained should be taken into consideration for choosing the best harvesting time of the crop (about 120 to 130 days after sown).

4. Conclusions

From the results it can be concluded the great superiority of the modern subsurface irrigation method on total biomass production of fiber sorghum as compared to the traditional surface drip irrigation method, due to the minimal evaporation losses and the better water distribution in the rooting zone.

Also with the subsurface drip method 48.4 l of irrigation water was used for the production of 1 kg dry biomass, whereas with the Surface method 66.1 l of water was used for proportionally equal values of total dry weights.

This irrigation method (subsurface) seems very promising and should be considered seriously in future feasibility studies of farming systems with low inputs such as those including bio-energy crops.

On the other hand, considering the attained maximum yield of fiber sorghum under supplemental irrigation viz. 14-18 t ha^{-1}, and under full irrigation reaching 33-38 t ha^{-1}, (roughly corresponding to 13.2-15.2 TOE), this crop seems very promising alternative commodity for biomass production in Greece, in the near future.

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