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Sweet sorghum for bioethanol production: Crop responses to different water stress levels

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ABSTRACT

Cultivation of sweet sorghum for the production of bioenergy is an attractive option to cope with the challenges of climate change and variability. In fact, on one hand it represents an interesting strategy of mitigation and, on the other, the use of drought resistant species could be considered as an opportunity of adaptation to the change of precipitation patterns. Anyway, when considering the production of agricultural feed stocks, particular attention should be addressed to the environmental sustainability of field production in order to avoid trade-offs in relation to food production, land use and pressure on the water resources. In this context, the cultivation of drought-tolerant energy crops as sweet sorghum (*Sorghum vulgare* (L.) var. Saccharatum) could be an interesting option. On the bases of these considerations, the current study had the aims i) to monitor the sweet sorghum growth and productive responses to different water treatments, in order to assess the extent of tolerance to constant water stress and ii) to assess the potential for first and second-generation bioethanol production obtainable from soluble sugars and residual biomass at two different development stages, flowering and physiological maturity.

Results show that the length of the growing period should be decided on the bases of the objective pursued.

If the objective is just the production of bioethanol, a longer cultivation period could be more suitable, but, on the contrary, if the objective is more addressed to an optimization of water, flowering should be considered the best harvest time.

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1. Introduction

Agriculture has a key role in both mitigation and adaptation to climate change because it represents a source of greenhouse gases (GHG) emissions due to field operations such as tillage and fertilizations, and, at the same time, it suffers the effect of the meteo-climatic variability to which adaptation is necessary in order to maintain good level of productions [1].

The strategies adoptable by the agricultural sector for contributing to the reduction of GHG emissions are mainly represented by the adoption of low-input cropping systems, the increase of the carbon stock in the soils and the sustainable production of biomass to bioenergy chains [2–7].

The special report of the Intergovernmental Panel on Climate Change on renewable energy, in fact, indicates the use of biofuels from energy crops among the mitigation measurements, and the European Community and national governments translated this concept into practice by creating specific financial subsidies and normative for supporting the production of bioenergy, now considered to all intents as an agricultural production. In particular, the Directive 2009/28/CE on the promotion of the use of energy from renewable sources indicates for 2020 the 10% target for renewable energy in transport that should be fulfilled through the use of sustainable biofuels.

Although some recent studies highlighted the critical issues related to the production of biofuels, particularly first-generation ones, there are promising technologies that seem to be able to break down the social and economical barriers, especially those generated by the competition with food production. In fact, the most debated problem is related to the use of feed stocks (edible crops), land and water resources for the production of biofuels that enter into competition with food production. Next generation biofuels are based on the use of lignocellulosic biomasses that comprise cellulose, hemicelluloses, lignin and other minor components. The existing methodologies for the saccharification of lignocellulosic biomass (acid and enzymatic hydrolysis) and for fermentation to ethanol (simultaneous saccharification and fermentation, and fermentation with thermophiles) are widely described and discussed in Refs. [8], and in the report of the International Energy Agency [9], where the biochemical and thermo chemical approaches are reported and analyzed. Based on this report, the typical ethanol yields recoverable from agricultural lignocellulosic biomass based on biochemical conversion, range between 110 and 270 L of fuel per ton of dry matter. High efficiency conversion has been obtained under controlled conditions in laboratory but not yet under industrial conditions [9].

Beside the continuous development of new technologies for the conversion of biomass into ethanol, when considering agricultural feed stocks, it is important to highlight the key role of a proper management of the farming systems to ensure the sustainability of the productions. In fact, the cultivation stage could be very impacting from an environmental point of view, caused by machinery, products (fertilizers and pesticides) used and irrigation applied for growing crops and maximizing yields. Among these impacts, the ones related to GHG emissions are often measured through Life Cycle Assessment studies (i.e. carbon footprint) [10–14], while the relationships with the water resources is probably most complicated to analyze [15,16]. In fact, agricultural production is strongly affected by changes in precipitation patterns due to climate change and variability and so water has become a critical issue and a limiting factor for the crops under rainfed systems, and for the water resource when irrigation is applied. Moreover, in situations of water scarcity such as in the southern part of Mediterranean, the cultivation of irrigated energy crops could also exacerbate the problem of competitiveness with food crops for the water use. Many studies confirm the negative trends of the precipitation, with a generally decrease of the total annual rainfall, the rainy days and the annual average water-table [2,17]. Based on these considerations, drought-tolerant energy crops should be the preferable choice in terms of both adaptation and environmental sustainability.

In this context, the cultivation of sweet sorghum (*Sorghum vulgare* (L.) var. Saccharatum) could be an interesting option. In fact, sweet sorghum is a species selected for its ability to accumulate soluble sugars into the stalk which could be mechanically extracted and then directly fermented for obtaining first-generation ethanol. Obviously, the maximization of sugar accumulation into stalks is at the expense of the panicle production. This feature makes the crop not suitable for food production and therefore not subject to problems of competition in that sense. Furthermore, after the juice and sugar extraction, the remaining biomass, which is a lignocellulosic residues, could undergo to specific treatments and be used for the production of second-generation bioethanol.

On the other hand, this crop is considered a water stress resistant species suitable for Mediterranean marginal sites [18,19], thanks to the particular morpho-physiological characteristics, that confer the drought tolerance, and to the C_4 photosynthetic system that allows an efficient CO_2 fixation and an outstanding dry matter accumulation [20–23]. Previous research demonstrated that sweet sorghum is well adapted to warm and dry Mediterranean regions in Europe under different conditions in Greece [24,25] and Spain [26]. In southern Italy, a study on sweet sorghum performance concluded that WUE is the highest encountered among C_4 crops, under both well watered and water limited conditions [27]. Results of researches carried on in Australia [28], India [29], and US [30] also confirmed that sorghum is better adapted to hot and semi-arid growing conditions than other energy crops, such as maize.

Another important characteristic of this crop is its adaptability to a wide variety of growing conditions, as showed in China [31] and south-central USA, where sweet sorghum appears to be a valuable alternative for land where dairy production has become unproductive, under erosive, droughty, sandy soils [32].

Considering the increasing demand for food, feed and bioenergy, and the consequent pressure on land and freshwater resources, the adaptability of sweet sorghum to marginal sites and the tolerance to drought conditions represent key attributes supporting the role of sweet sorghum as a source of bioenergy.

On the bases of these considerations, the current study had the aims i) to monitor the sweet sorghum growth and productive responses to different water treatments under