Maize and Sorghum Biomass and Protein Accumulation Under Adequate and Limited Supply of Water and Nitrogen in Greece

S.V. Archontoulis[1,2], P.C. Struik[1], J. Vos[1], N.G. Danalatos[2]
[1]Wageningen University, Centre for Crop Systems Analysis, Wageningen, The Netherlands
[2] University of Thesaaly, Lab. of Agronomy and Applied Crop Physiology, Volos, Greece
Email: sarchont@gmail.com

Maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* L.) Moench) are two important cereals for grain, forage and bioethanol production. In Greece, maize is widely cultivated while sorghum is only a marginal crop. Maize productivity strongly depends on irrigation and nutrients supply. In the Thessaly Plain (central Greece), the country's major lowland, irrigation water availability is in decline, reducing considerably crop yields and thus farmer profit. Sorghum is more tolerant to water deficit than maize (Kavadakis et al., 2000; Farre and Faci, 2006). Sorghum might therefore be a good alternative to maize for forage production. Recently, Danalatos et al. (2009) compared sorghum and maize under optimum and stress conditions in central Greece, and found that sorghum produced much higher dry biomass yields than maize (35 vs. 20 t/ha) under stress and non-stress conditions. However, sorghum hybrids were late maturing, while the maize hybrid used was of medium maturity, in line with the local practice.

This paper builds on the work of Danalatos et al. (2009). We compared the same sorghum hybrid (cv. H133) with the late-maturing maize hybrid Dekalb under conditions with adequate and with limited supply of water and nitrogen in central Greece. The specific objectives of this paper are (a) to assess the production potential of late cultivars of the two crops and (b) to quantify the dynamics of protein accumulation of both crops, which is fundamental for forage production.

Methodology

The field experiment (2 crops × 2 input levels × 4 replicates) was carried out in the Thessaly Plain, central Greece (Karditsa; 39°25' N and 22°05'E) in 2009. Sowing was done on May 15th; 50% emergence occurred 6 days later. The soil was a deep, fertile loam, classified as Aquic Xerofluvent. Maize and sorghum productivity were investigated under adequate (thereafter A) and limited (thereafter L) input conditions. The A-plots received 200 kg N/ha as fertilization and 479 mm as irrigation water (11 applications; Fig. 1a). The L-plots received 100 kg N/ha and 230 mm as irrigation water (5 applications; Fig. 1b). Both plots received 100 kg P and 100 kg K/ha.

Irrigation was applied via a drip irrigation system. A-plots irrigation full matched the maximum evapotranspiration (ETm) as determined by class-A pan evaporation method. Crop growth and biomass and nitrogen productivity per plant component (stem, leaves, grains and cobs) were measured in nine destructive samplings. Sub-samples from each harvest were analyzed for nitrogen concentration using the Kjeldahl method, and data were expressed in crude protein by multiplying the nitrogen concentration by 6.25. Standard weather data were recorded hourly in an automatic meteorological station. All data sets were subjected to ANOVA using GenStat software.

Results and discussion

During summer, mean air temperature (range: 18–31°C) and incident global radiation (25.2 MJ m^{-2} d^{-1}) were at satisfactory levels to support maximum leaf assimilation rates. ETm was estimated at 540–600 mm for both crops. Crop water requirements were more than covered in the A-plots (including precipitation) and only partially covered in the L-plots (65%; Fig. 1a). Maize canopy remained closed (LAI>3) for approximately 70 days (180–250 Julian days) in A-plots and for 40 days in L-plots (180–220 JD). The sorghum canopy, however, was fully closed for about 90 days (180–270 JD) at both levels of input, but peak LAI values were higher for the A plots (5.9 m^2 m^{-2}) than for the L plots (4.5 m^2 m^{-2}).

Sorghum responded to deficit of water and nitrogen by rolling the leaves, while maize responded by advanced senescence and leaf litter. This difference in behaviour explains the observed differences between the two crops in stay-green behaviour. Biomass yields per treatment are illustrated in Fig. 1b. Crop growth rates during the closed canopy period varied from 224 (maize–L) to 373 (sorghum–A) kg ha^{-1} d^{-1}. These rates of increase resulted in maximum dry matter yields of 18.5, 27.5, 25.9 and 31.1 t ha^{-1} for maize–L, maize–A, sorghum–L and sorghum–A, respectively ($P<0.001$; LSD=6.67 t ha^{-1};

Fig. 1b). Sorghum–L attained similar biomass yield as maize–A, pointing to the superiority of the first crop for biomass production under lower inputs. Fig. 1c illustrates the dynamics of nitrogen concentration per plant component and per treatment. Maize kernel and cob nitrogen concentration were 1.5% and 0.6% respectively.

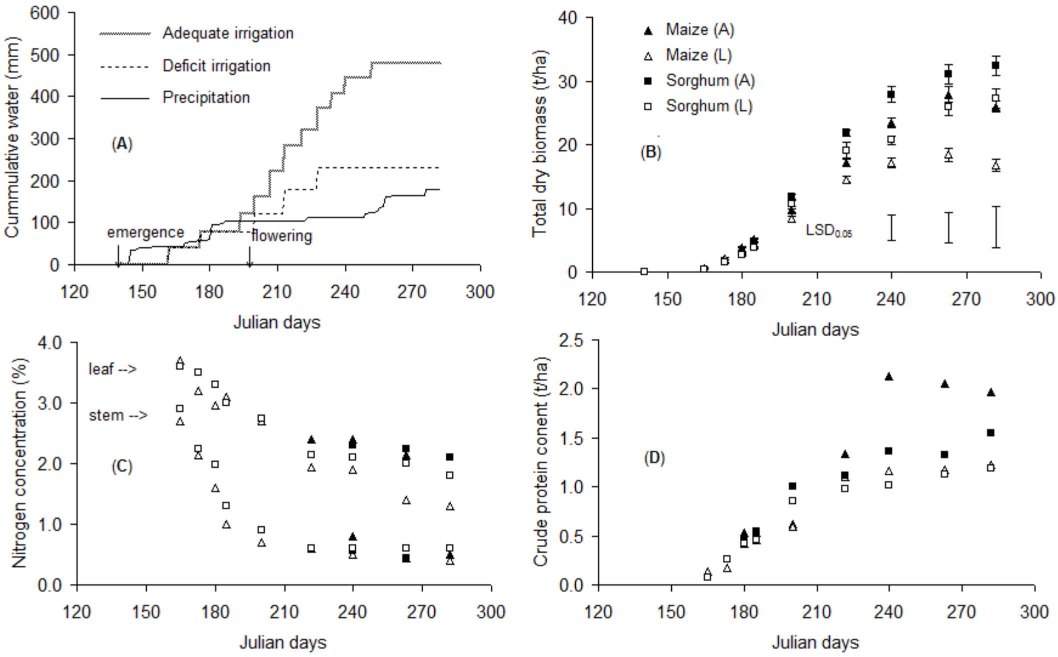

Fig. 1: Cumulative adequate irrigation, deficit irrigation and precipitation water (panel A), above ground total dry biomass (panel B, means ± standard error of means; vertical bars indicate $LSD_{0.05}$), green leaf and stem nitrogen concentrations (panel C; some symbols are overlapping), and total crude protein content (panel D) as a function of Julian days, in central Greece in 2009. A=adequate supply of water and nitrogen; L=limited supply of water and nitrogen.

From emergence to August 10^{th} (222 Julian days) protein content increased almost linearly (15.9–20.8 kg protein ha^{-1} d^{-1}) in all treatments, reaching an average value of 1.13 t protein ha^{-1} (Fig. 1d). Beyond this period, sorghum crops did not substantially increase their protein contents, although their biomass yields further increased (Fig. 1b). In contrast, the protein content of maize–A continued to increase due to rapid accumulation in the kernels reaching a peak protein yield of 2.1 t ha^{-1} at the end of August, a common harvest date for forage maize at the study site.

Concluding, late-maturing maize hybrids produced 12% lower biomass- and 36% higher protein yields under non-limiting conditions than late-maturing sorghum hybrids. Under limiting conditions (more representative scenario), maize produced 28% lower biomass- and attained protein yields similar to sorghum. Our work indicates that sorghum could be considered as an alternative to maize for forage production, particularly in the semi-arid zone (Thessaly Plain) where water deficit is pronounced. However, more studies should emerge screening sorghum cultivars, examining more quality traits and economic aspects.

References

Danalatos NG, Archontoulis SV, Tsibukas K, 2009. Comparative analysis of sorghum vs. corn growing under optimum and under water/nitrogen limited conditions in central Greece. Proceedings of the 17th European Biomass Conference, Hamburg, Germany, 538–544.

Farre I, Faci JM, 2006. Comparative response of maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* (L.) Moench) to deficit irrigation in a Mediterranean environment. Agricultural Water Management, 83: 135–143.

Kavadakis G, Nikolaou A, Panoutsou C, Danalatos N, 2000. The effect of two irrigations and three fertilizations rates on the growth and productivity of two sweet sorghum cultivars, in central Greece. Proceedings of the 1st European Biomass Conference, Sevilla, Spain, 1737–1740.