European Journal of Agronomy 97 (2018) 38–47

Contents lists available at ScienceDirect

European Journal of Agronomy

journal homepage: www.elsevier.com/locate/eja

Sugar beet development under dynamic shade environments in temperate conditions

S. Artru[a,*], L. Lassois[a], F. Vancutsem[b], B. Reubens[c], S. Garré[a]

[a] University of Liège, Gembloux Agro-Bio Tech, TERRA Teaching and Research Center, Passage des déportés 2, 5030 Gembloux, Belgium
[b] IRBAB-KBIVB, Molenstraat 45, B3300 Tienen-Tirlemont, Belgium
[c] Flanders Research Institute for Agriculture, Fisheries and Food (ILVO), Burg. Van Gansberghelaan 109, 9820 Merelbeke, Belgium

ARTICLE INFO

Keywords:
Light interception
Agroforestry
Spring crop
Sugar beet
Petiole elongation
Sugar yield
Shoot morphology

ABSTRACT

In Wallonia (Belgium) almost half of the arable land undergoes a four-year crop rotation. Winter crops often follow spring crops within the rotation scheme. This is a challenging context to implement silvoarable agroforestry (AF) systems, in terms of species choice, plot design, and tree management, since the periods of crop resource capture clearly differ. AF is defined here as the deliberate introduction of trees in the cropped area. Combining spring crops with trees induces an important overlap of the growing period of both plants which has an impact on one of the primary resources for both plants: light. In this study, we monitored an important spring crop for the region, sugar beet (*Beta vulgaris* L.). We quantified the impact of the shade environment on sugar beet morphology, growth dynamic, productivity and quality. We used artificial shade to isolate the impact of shade from other possible interactions in agroforestry systems. The field experiment was conducted over two consecutive years (2015 and 2016) on the experimental farm of Gembloux Agro-Bio Tech, Belgium. We installed the shade structures so as to reproduce a North-South and East-West tree line orientation. The experiment simulated canopy shade of late-flushing hybrid walnut by overlapping military camouflage netting. In 2015, the North-South orientation induced two distinct shade conditions: periodic shade (PS) and continuous shade (CS). In 2016, the East-West orientation created two periodic shade treatments, one during the morning (PS_{am}) and one in the afternoon (PS_{pm}). In both experimental years, shading was imposed from mid-June until harvest, resulting in 132 days of shade in 2015, and 140 days in 2016 on a growing season of 192 (2015) and 188 (2016) days in total. Sugar beet under shade tended to produce longer petioles. In 2015, at the first sampling date, we observed a higher specific leaf area and single leaf area under the CS and PS treatment, while there were no differences in 2016. All the shade treatments significantly changed the dry matter partitioning between the sugar beets compartments. Under the shade treatments, the quantity of biomass allocated to the leaves was significantly reduced as compared to the proportion of biomass for the petioles. Likewise, quantity of root dry matter formed per gram of shoot dry matter was reduced under shade. Thus, at harvest, all the shade treatments significantly reduced the final root dry matter and sugar yield. Furthermore, sugar beet quality, and more specifically sugar extractability, was affected by shading but to a lesser extent than for the final root dry matter and sugar yield.

1. Introduction

In Europe crop rotation remains a common agricultural practice within which a winter crop often follows a spring crop (Leteinturier et al., 2006). Among the different spring crops, sugar beet (*Beta vulgaris* L. ssp. *vulgaris*) is commonly cultivated in Europe and represents around 50% of the global sugar beet production, ranking the EU among the world leaders (Eurostat, 2015). In Belgium, this crop accounted for 5% and 4% of the utilized agricultural area in 2014 and 2015, respectively. According to Leteinturier et al. (2006), sugar beet remained the principal crop preceding winter wheat within the crop sequence between 1997 and 2003, whatever the crop rotation duration.

Studies on the influence of seasonal weather variability on sugar beet development recognized that amongst the different environmental variables, the amount of available light for the crop is a predominant factor driving the biomass accumulation after crop canopy closure (Scott and Jaggard, 2000). Nevertheless, crop growth not only depends on the quantity of global radiation cumulated over the whole growing season, but also on the dynamics of its availability throughout the growing season and its interaction with the stage of crop development,

* Corresponding author.
E-mail address: sidonie.artru@uliege.be (S. Artru).

https://doi.org/10.1016/j.eja.2018.04.011
Received 6 March 2017; Received in revised form 16 April 2018; Accepted 20 April 2018
Available online 26 May 2018
1161-0301/

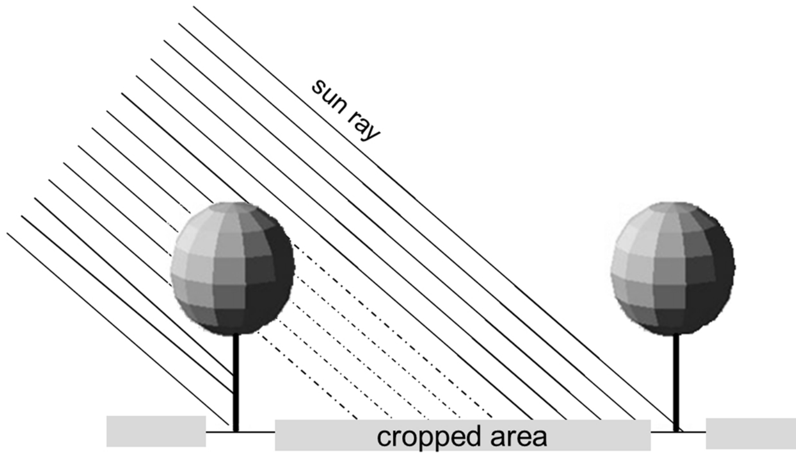

Fig. 1. Schematic representation of the silvorarable agroforestry systems considered in this study.

as well as on the light quality (red to far red ratio and proportion of direct and diffuse light). In fact, several studies have shown that a number of physiological and biochemical adaptations occur when crops are subjected to a shady environment, and that some of these adaptations are then translated by the crop into morphological changes in order to optimize light capture and use (Valladares et al., 2007, 2003). Within silvoarable agroforestry systems − defined here as the deliberate introduction of tree lines within a cropping area − the presence of trees adds a level of complexity in terms of spatio-temporal dynamics for resource-use (Fig. 1).

Previous work on sugar beet quantified the influence of individual weather variables or different weather conditions on growth and yield in a monocrop situation throughout the growing season (Albayrak and Çamaş, 2007; Kenter et al., 2006; Milford et al., 1985; Scott and Jaggard, 2000; Werker and Jaggard, 1998). Nevertheless, few attempts have been made to describe the performance of sugar beet as part of agroforestry systems and the transferability of results from monocropped field situations to mixed systems is limited (Mirck et al., 2016).

The effect of the individual weather variables is often tested by applying a stress condition during the whole crop development rather than at a specific time during the growing season or at a specific time of the day, as observed under trees. Nevertheless, within an agroforestry system the light availability for the crop varies over the day, month and year depending on the path of the sun, tree planting density, tree row orientation, silvicultural practices and tree phenological stage (Leroy et al., 2009; Liu, 1991; Talbot and Dupraz, 2012).

The objective of this study was to quantify the response of sugar beet to a dynamic shade environment using such an artificial shade structure during different development stages.

2. Material and methods

2.1. Field experiment

The experiment was conducted during two growing seasons (2015 and 2016), at the experimental farm of Gembloux Agro-Bio Tech (50°33′ N, 4°42′E), in the Hesbaye region, Belgium. Since the different fields of the farm follow a specific crop rotation scheme, we moved our plots within those fields in order to monitor sugar beet during two subsequent years. In both locations, the soil is classified as a Luvisol (FAO, 2014). The climate is temperate maritime, with an average annual temperature of 9.96 °C and mean annual cumulated rainfall of 805 mm over a 30 year period (1986–2015).

Sugar beet (*Beta vulgaris* L., var. Lisanna KWS in 2015 and var. Leonella KWS in 2016) was sown on April 10th, 2015 and April 21th, 2016, respectively (± 111 seeds/ha). The crop rows followed an East-West orientation in 2015 and a Northeast-Southwest orientation in 2016 in order to mimic the pattern of two distinct tree line orientations. In 2015, the preceding crop was an intercropping mix of winter wheat and winter pea (*Pisum sativum*), followed by a winter catch crop, i.e. mustard (*Sinapsis alba*). In 2016, the preceding crop was winter wheat followed by a winter intercropping mix of mustard and pea. The sugar beet seeds used in this experiment were pelleted with two fungicides and one insecticide. Fertilization followed the conventional practice applied in Belgium. In 2015, one dose of liquid nitrogen fertilizer (104 kg N/ha) was applied two days before sowing. In 2016, one dose of liquid (41 kg N/ha) and one dose of solid nitrogen fertilizer (13 kg N/ha) were applied 17 and 8 days before sowing, respectively. For both growing seasons, the main agronomic practices were mechanical weeding and the application of herbicides. Sugar beet was harvested on October 19th, 2015 and October 26th, 2016, respectively.

2.2. Experimental design

In both growing seasons, shade levels were obtained by adjusting shade layers on a greenhouse tunnel structure (8 m wide, 35 m long and 2 m in height) (Fig. 2a). In 2015, the structure was set up in East-West orientation with a shade layer applied on the south face. This orientation leads to a continuous shade (CS) treatment under which crop experienced shade throughout the entire day and a periodic shade treatment (PS) under which the crop was submitted to an intermittent shade which varies during the day. In 2016, the greenhouse structure follows a Northeast-Southwest orientation with a 2.5 m shade layer band centered on the top of the structure (Fig. 2a). This set up results in two distinct periodic shade treatments, one lead to a shade period in the morning (PS_{am}) and the other one in the afternoon (PS_{pm}). For both experimental years, we also followed a no shade treatment (NS) defined as the control plot, receiving 100% of the available light. By changing the orientation and shade structure, we were able to monitor a large range of periodic shade types, which helps us to better understand the different shade environments produced in real agroforestry systems.

Camouflage net was used as shade material to reproduce a fluctuating sun/shade pattern, the holes in the cloth producing a combination of direct and diffuse light patches. The artificial shade was designed to mimic the shade dynamics of a hybrid walnut and was adapted through time to follow the development of tree-foliage in a monitoring plot in Belgium (see next paragraph). Hybrid walnut was selected as reference tree given its late-budding characteristic.

The layout included four replicate blocks per treatment each made up of three subplots of four adjacent sowing rows of 1.5 m length with a distance of 0.45 m between each row, so 2.7m^2 per subplot (Fig. 2b). During both growing seasons three sampling campaigns were performed. At each sampling date, one sub-plot per replicate was harvested, i.e. four subplots per treatment (Fig. 2b).