DEALING WITH CROP ROTATION IN AGROFORESTRY: THE IMPACT OF SHADE ON WINTER WHEAT AND SUGAR BEET GROWTH AND YIELD UNDER BELGIUM CONDITIONS

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Introduction

In Wallonia, Belgium, almost half of the utilized arable agricultural area is managed applying a 4 year crop rotation. Winter wheat (*Triticum aestivum* L.) and sugar beet (*Beta vulgaris*) remain amongst the most important crops, representing respectively 38 and 39% of the arable surface (Leteinturier et al., 2003). Traditionally, a winter crop (October to August) follows a spring crop (March-April to October) in the rotation. Such a 4-year crop rotation in combination with agroforestry systems challenges the tree plantation layout and species choice in terms of spatio-temporal dynamics for resource-sharing. In successful agroforestry systems, complementarity may result from niche differentiation for resource capture, either in space (e.g. different root depth) or time (e.g. different phenology). It remains difficult to obtain a clear overview for all the design possibilities, crop rotations, soil and climate conditions.

Light might be the principal limiting resource for crops growing under trees of silvoarable agroforestry systems subjected to Belgian soil and climate conditions. Dufour et al. (2011) showed that a high phenological time-lag between tree and crop, which is the case with a winter crop and late deciduous tree, is optimal for this resource use in temperate agroforestry systems.

But how about sugar beet? The general aim of this study was to quantify the efficiency of winter wheat and sugar beet growth, productivity and quality under late shaded conditions provided by an artificial shade system. In order to reproduce the diversity of possible shade environments observed under real agroforestry systems, the two crops have been subject to two distinct shade conditions: a continuous and a periodic shade. The results will be interpreted in the context of crop rotations in Belgium.

Material and methods

Winter wheat (cultivar Edgard) and sugar beet (cultivar Lisanna KWS) were sown on the land of the experimental farm of Gembloux Agro-Bio Tech in Belgium (50°24' N, 5°27'E) in October 2014 and March 2015 respectively. An artificial shade structure was installed to induce three shade conditions corresponding to three distinct daily shade dynamics. The continuous shade (CS) treatment received a reduced proportion of light throughout the entire day. The periodic shade (PS) treatment corresponded to an intermittent shade on the plot varying within the day. The no shade (NS) treatment corresponded to the control plot in which 100% of the incident light is transmitted to the crop. The two shade levels were obtained by covering the north face of a greenhouse tunnel structure with military cloth. The tunnel was installed in the field in East-West orientation. Light at the crop canopy level was measured by 5 quantum sensors installed along the shade gradient (CS300 – Campbell Scientific Inc., USA) (Figure 1). The installation of the artificial shade structure and the shade layers follow the phenology of a hybrid walnut tree situated in Jenneret, Belgium. During the growing seasons, crop phenology, biomass development and final yield were monitored in the field for the two crops. For sugar beet, 3 sampling campaigns have been conducted during the cropping season, in 1st week of august, in1st week of September and at harvest to obtain the seasonal pattern of the root biomass and the sugar content dynamics.

Figure 1: Artificial shade structure above winter wheat (a) and sugar beet (b). The right frame corresponds to the general lay out of the experimental device : the three modalities (CS, PS, NS) and the light sensors position located along a north-south gradient.

Results

For winter wheat, at the scale of the growing season, we applied shade 66 days before harvest on a total growing period of 292 days. According to the crops phenological development, winter wheat experienced equivalent light conditions before the maximum leaf area stage (LAI). From LAI to flowering (24 days), the transmitted global radiation was reduced by 22 % under CS treatment and it varied from 19 % to 11 % under the PS treatment. Thus, from flowering to harvest (55 days), the reduction reached 65 % under CS treatment and 55 % to 35 % under the PS treatment. LAI was not significantly affected by the shade treatment (CS, PS) as compared to NS. For all the treatments, the total aboveground biomass accumulation (g/m^2) was significantly related to the global radiation cumulated (MJ/m^2) by the crop. Thus, the NS treatment results in the highest grain yield. A maximum grain yield reduction was observed for the CS treatment (-45%), while the PS treatment led to an intermediary yield reduction (-25%). The decrease of grain yield in response to both shade treatments is ascribed to a significant reduction of grain weight and number of grains per m^2. For an equivalent number of grains per m^2, treatments differ in terms of grain size, with a higher proportion of big grains (<2.8 mm) under the NS treatment. Thus, the reduction of transmitted global radiation mainly affects grain filling processes. Furthermore, grain protein content significantly increased with increasing shade, which equals an increased grain quality. Nevertheless, this did not compensate the decrease in final grain yield at the plot scale. Total protein yield (t/ha) also declined with increased shade application.

Sugar beet received 132 days of shade (out of a total of 192 days) before harvest at the scale of the growing season. Being a biennial crop, the phenological stages are less noticeable than for winter wheat. Nevertheless, we observed that the first layer of shade was applied before canopy closure. The CS treatment led to a reduction of transmitted global radiation from 28 %, 67 % and 75 % for the three sampling dates respectively. For the PS treatment these reductions reach 14 %, 47 % and 56 %. The shade treatment induced morphological changes. On average, shade led to taller plants with thinner leaves, but no differences in LAI for two of the sampling dates. The sugar beet plants adapted they shape under shade with more erected leaves. Moreover, the overall growth rate significantly decreased with shade treatment with a higher reduction of root growth than leaf growth for PS. For the CS treatment, there are no significant differences in roots fresh weight between the three sampling dates. At harvest, this results in a significant root yield reduction: 72 % and 35 % respectively for CS and PS as compared to NS. The final sugar yield follows the same trend with a decrease of 70% and 38% respectively for CS and PS as compared to NS.

Discussion

The experimental setup presented in this study reproduced and isolated the effect of the heterogeneous spatio-temporal patterns of light observed under trees in an agroforestry system using an artificial shade structure. Both crops responded to the light reduction with yield reductions and the literature confirms this is no exception (Chirko et al., 1996; Dufour et al., 2013; Li et al., 2010; Mu et al., 2010; Ozkan, 1971). Nevertheless, the effect of the light reduction highly depends on the phenological stage during which shade is applied as well as the duration of the period in which the incident light is reduced. Furthermore, the variables affected by the shade treatment will differ between crops. In this study, an aboveground acclimation process of sugar beet takes place, resulting in erected leaves or higher specific leaf area. Some authors have shown that these adaptations enhance light capture (Ozkan, 1971) and optimize photon absorption in low light conditions (Evans et al., 2001). Nevertheless, these adaptations are not sufficient to fully compensate light reduction under the shaded treatment. For wheat, no such morphological adaptation was observed as the shade treatment was applied after the LAI_{max} phenological stage and the reduction of final yield under the CS treatment was lower than the one observed for the sugar beet. Some authors observed that physiological and morphological compensation processes occur on winter wheat when applying shade (from jointing to maturity and induce a final yield increase. Such considerations need to be taken into account for breeding programs in order to develop shade tolerant species adapted to agroforestry practices.

In view of the large diversity of agroforestry system, it remains difficult to associate the current experiment to a specific agroforestry system light environment. Firstly, the military cloth does not entirely reproduce shade under tree leaves and secondly, the combination of tree age and field lay-out may result in various situations corresponding to our shade treatments. Nevertheless, the artificial shade set up creates an extreme range of shade environments. Thus, the CS treatment allows to reflect a strong shade environment corresponding to old trees and high plantation densities, or tree rows with an east-west orientation inducing a continuous shade during the day on the plot. This configuration of high density with canopy closure between the trees rows remains unrealistic considering the actual agricultural machinery especially for sugar beet requiring at least 50 m tree spacing. The PS treatment is more realistic, simulating lower shade environments corresponding to younger trees, and/or more open plantation densities.

Dealing with rotations containing winter and spring crops within an agroforestry system complexifies stand design and management. In this study, the experimental set up isolated the effect light. This gives us a first insight of the behavior of two specific crops growing under shade context, but does not take into account the trade-offs that potentially occur in real agroforestry systems including effects of microclimate, soil moisture and nutrients, etc.. In future research, the present artificial shade experiment needs to be accompanied by research on these other tree-crop-environment interactions to have an overall view of the system functioning. Furthermore, it also remains necessary to include tree productivity in the research reflection in order to evaluate to rate of compensation of crop yield decrease.

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