Effect of shade on production and grain yield in greenhouse wheat varieties

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Abstract The effects of climate change threaten food security by affecting the production and quality of crops that are part of the world's food base, such as wheat. The crop-tree association can act as a tool to mitigate and adapt to climate change, and it is important to analyze the influence of the shade cast by the tree canopy on the yield of important global cereals. This study analyzes the effect of shade (IS: intermediate shade and HS: high shade) on grain yield (GY), straw yield (SY) and number of grains m^2 (G m^{-2}), in 17 varieties of winter wheat, with growth cycles of different lengths (early, medium, late). The wheat was sown on two late dates (December 2016 and January 2017), under controlled greenhouse conditions. Straw yield decreased in shady conditions in medium and later varieties, sown in January. Only a decrease of grain yield and number of grains was observed when late varieties were sown in January when HS was applied to plants. These results seem to indicate that the variation in light intensity has a lesser effect in those varieties that are sown in December.

Keywords: *Triticum aestivum* L.; commercial varieties; shade, precocity, sowing date

1. Introduction

The effects of climate change, as well as the effect of conventional agriculture, heir to the Green Revolution, on available resources have contributed to the decline in global production of the foods that form part of the world's food base. It generates the need to adopt sustainable management measures for the territory and its components in the medium and long term. For this, sustainable practices are proposed that combine integrated knowledge and organic and traditional management techniques such as silvoarable agroforestry systems. That combine intercropping with timber products (McAdam et al. 2009, Mosquera-Losada et al. 2009). There are multiple benefits resulting from this interaction, the tree provides protection to the crop against: pests, sudden changes in temperature, sudden changes in precipitation, loss of nutrients due to runoff, windbreaks, among others (Schoeneberger et al. 2012). However, the lack of knowledge about crop yield and production when competing for resources with trees (i.e., light), can be a real obstacle to the choice of silvoarable systems as a management tool, as contemplated by Eichhornm et al. (2006). Under the tree canopy, crops develop in a heterogeneous light environment which, together with other factors such as planting frame, wind, crop area location, crop planting date, silvicultural practices, and tree phenological stage (Leroy et al. 2009; Talbot and Drupaz, 2012) can (in a negative way usually) affect cereal yield and production. The date of application or appearance of shade, as well as the level of intensity are going to be two factors affecting crop morphology, yield, production, and quality depending on which ontogenetic stage is affected (Savin and Slafer, 1996; Chirko et al. 1996; Dufour et al. 2013).

In this study, the influence on yield and grain yield of artificial shade applied to 17 wheat varieties of different phenological cycle (early, medium, early), sown in December (2016) and January (2017), was analyzed.

2. Methodology

This study was conducted in the greenhouse of the Polytechnic School of Higher Engineering of the University of Santiago de Compostela in Lugo. The experimental design was a randomized complete block with three treatments and four replicates per treatment. Seventeen wheat varieties of different earliness (Early, Medium, Late) were sown on two sowing dates: December 2016 and January 2017 and received three light intensities (NS= No Shading; IS=Intermediate Shading; HS= High Shading) in April 2017, to simulate the shade provided by the tree canopy of those trees that sprout early in temperate zones, such as poplar. Shade was artificially simulated through a green polyethylene mesh of two different hole sizes (0.0075 cm^2 and 0.0026 cm^2) for simulating IS and HS conditions, respectively. The wheat varieties were sown in plant pots of (15x15x30 cm), which were previously filled with a substrate composed of peat (58%) and perlite (42 %) and fertilized with 10 cm^3 NPK (10:5:5) in March 2017. After harvest, all plants were labeled and transported to the laboratory. The plant was fractionated into spike and stem and each fraction was weighed for fresh and dry matter obtained (40°C x 72 hours). The aerial biomass was divided between straw biomass (stem and rachis spike) and grain biomass. The grains per spike were also counted and weighed. The 100-weight grain (100 WG, g) was also performed; it was determined by randomly choosing a representative sample of 100 grains of the harvested grain from each experimental unit.

Straw yield (SY, g m^{-2}) was estimated by dividing dry weight biomass stem and rachis spike per m^2 ($10000 \div (0.11^2)$).

The **number of grains m^{-2} (G m^{-2})** was calculated by multiplying $YG \div 100$ and dividing this amount by the weight of 100 grains $GM^2 = (RG \times 100) \div 100WG$).

An ANOVA was carried out for statistical analysis using IMB SPSS version 23 (2014) for Windows. Tukey's significant difference ($P \leq 0.05$) was calculated if the ANOVA was significant. Simple linear regression equations were used to determine the relationships between variables.

3. Results

Variation in light intensity produced changes on total biomass of spike. The straw yield (steam and rachis spike yield, g m^{-2}) under shaded conditions seemed to have a tendency to decrease; however, no significant differences were found between the varieties sown in December. Significant differences ($p<0.05$) were only observed in medium and late varieties, (Figure 1), that were sown in January under HS compared to IS (46.10-64.24% reduction, respectively).

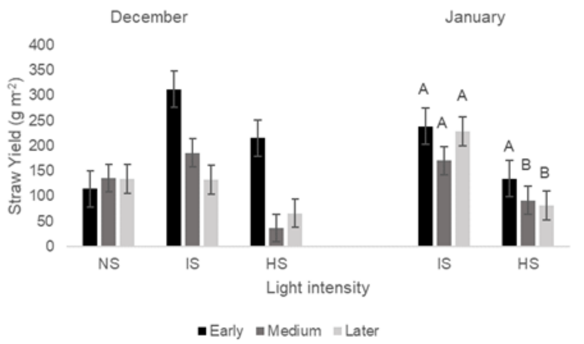

Figure 1. Variation in Straw Yield (stem+ rachis biomass) of wheat varieties, sown in December and January, under different degrees of light intensity. (NS= no shade, IS= intermediate shade; HS= high shade), applied in April. Significant differences were found between varieties under S conditions in January sowing date. Different letters indicate differences between in the same variety under different light condition, with the letter *a* assigned to high values ($p<0.05$). The lack of letters indicates that no significant differences were found between treatments for the same variety.

When analysing Grain Yield (g m^{-2}) the same trend found for the total accumulated biomass in straw was observed. Under shading conditions, the biomass in grain and in the spike decreased. Nonetheless, a significant variation between shade intensities was only encountered for late varieties sown in January ($p<0.001$), with a reduction of 73.19% when shade was more intense, Figure 2. The same trend was observed for G m^{-2}, Figure 3. Only a grain biomass reduction was found in late varieties, sown

Grain yield (YG, g m^{-2}) was estimated assuming a row distance of 11 cm as the traditional planting distance in the area. The total and fractional biomass per plant pot was multiplied by the assumed grain density per m^2 ($10000 \div (0.11^2)$).

in January, when HS was applied (66.85% reduction compared to IS).

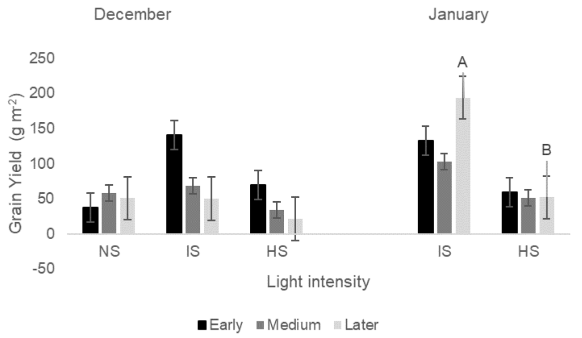

Figure 2. Variation in Grain Yield of wheat varieties, sown in December and January, under different degrees of light intensity. (NS= no shade, IS= intermediate shade; HS= high shade), applied in April. Significant differences were found between varieties under S conditions in January sowing date. Different letters indicate differences between in the same variety under different light condition, with the letter *a* assigned to high values ($p<0.05$). The lack of letters indicates that no significant differences were found between treatments for the same variety.

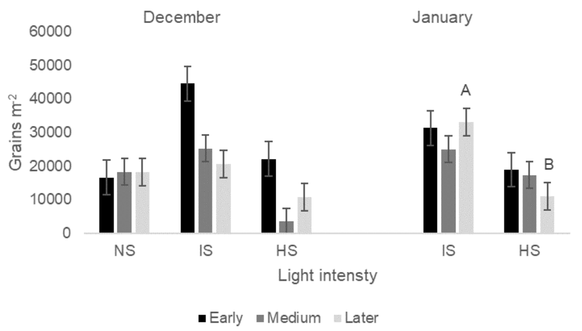

Figure 3. Variation in Grain m^{-2} of wheat varieties, sown in December and January, under different degrees of light intensity. (NS= no shade, IS= intermediate shade; HS= high shade), applied in April. Significant differences were found between varieties under S conditions in January sowing date. Different letters indicate differences between in the same variety under different light condition, with the letter *a* assigned to high values ($p<0.05$). The lack of letters indicates that no significant differences were found between treatments for the same variety.

Grain yield was positively and significantly associated with straw yield in IS (December, R^2 (IS)= 0.69; ($p<0.0001$); January, R^2 (IS)= 0.54; ($p<0.0001$)) and in HS (December, R^2 (HS)= 0.53; ($p<0.001$); January, R^2 (HS)= 0.82 ($p<0.0001$), as shown in Figure 4. In turn, the number of grains m-^{2} was positively correlated with straw biomass under HS conditions, for both planting dates. Under HS conditions observing an increase in the varieties sown in January (R^2 (IS)= 0.72; ($p<0.0001$); R^2 (HS)= 0.39, ($p<0.001$)).

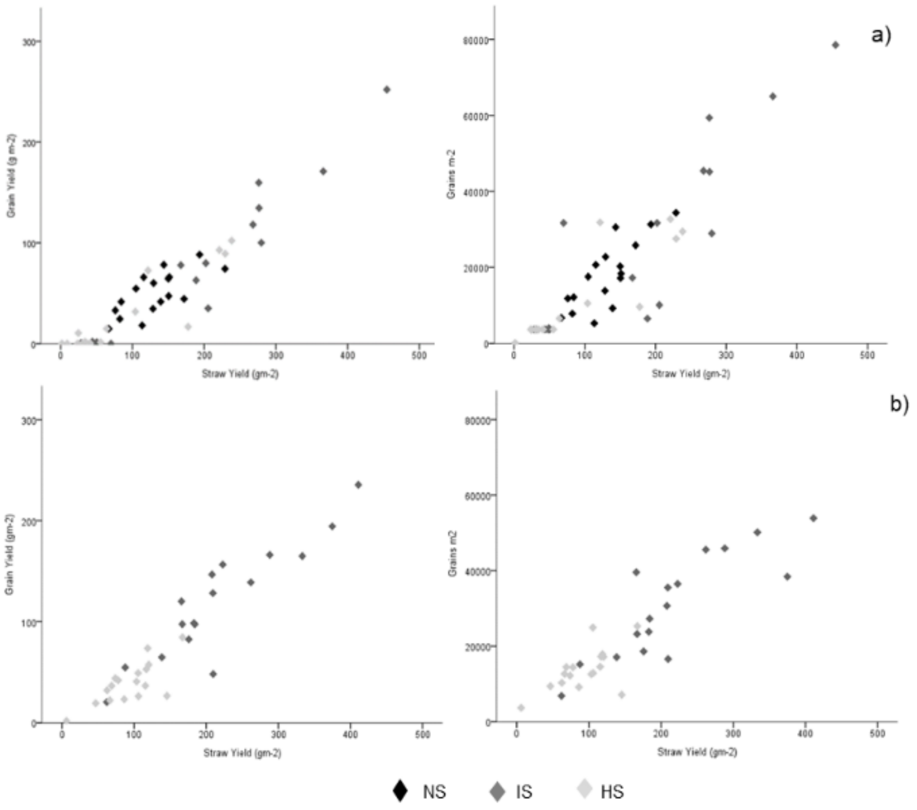

Figure 4. Relationships between different components of aboveground biomass of wheat varieties, sown in December (a) and January (b), under different degrees of light intensity. (NS= no shade, IS= intermediate shade; HS= high shade), applied in April. letters indicate differences between in the same varieties under different light condition, with the letter a assigned to high values ($p<0.05$). The lack of letters indicates that no significant differences were found between treatments for the same variety.

4. Discussion

The analysis of the two shade intensity treatments combined for each planting date and variety cycle showed the effect that variation in light intensity has on yield and grain yield. No statistically significant evidence was found to show that the interaction between planting date and earliness had a joint effect on yield and/or grain yield. The observed trend shows a reduction in GY under shading conditions, being higher under HS conditions (although this effect was not significant). Unlike the results observed in Arenas-Corraliza et al., 2019, in whose study under greenhouse conditions they observed a 19% increase in GY, for wheat varieties grown under intermediate shade (90% light intensity) and high shade (50% light intensity) conditions, with respect to that observed under full radiation conditions. On the other hand, Xu et al. (2016) showed in their study that no significant differences were evidenced in terms of grain yield increase under shade conditions below 90% light radiation.

Varieties with longer cycles showed greater sensitivity to the reduction in light intensity. Arenas-Corraliza et al. (2019), found no evidence that earliness was a significant factor in grain yield under shade conditions, as observed in this study in varieties sown in December, a result that differs from that observed in varieties sown in January. The absence of a control in January, due to fungal infection problems, prevented us from analyzing the behavior of the varieties under light radiation conditions, limiting this study to the observation and comparison between shade intensities.

Based on these results we can conclude that cereal species such as wheat, under high irradiation conditions, can be benefited from partial shade. The decrease in cereal yield can be explained by lower irradiation and/or the interaction of other factors such as sowing date, as shown in their study by Ali et al. (2010) where authors found that grain yield decreases as sowing is done later. In contrast to the results observed by Ali et al. (2010) in the present study, significant differences were found in the varieties that were sown in January; no significant differences were found for yield in varieties sown in December. Another factor that should be paid attention to is the duration of the phenological cycle since the alteration of the sowing date, can produce a decrease in the duration of the phases by the interaction with other factors such as temperature, and photoperiod. Artru et al.

(2017) showed how the conditions generated under the tree canopy, in agroforestry systems, among which the decrease in light intensity can influence the most critical ontogenetic phases of cereal development such as spiking-flowering, with the consequent loss of yield and grain quality.

5. Conclusion

Light is an important factor affecting yield and/or grain yield. A positive and significant correlation is observed between straw and grain number with grain yield. The trend that was observed is a decrease in GY as shade intensity increases.

Not all varieties are equally tolerant to shade conditions. It was the late and medium varieties, sown in January, that showed less tolerance to S conditions, more specifically HS conditions. Therefore, this factor should be taken into account when recommending the selection of a variety for field cultivation, together with the sowing date, the physiological characteristics of the crop and the interaction with other abiotic factors, which leads to further research in this line of investigation.

6. Acknowledgments

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