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## Evaluation of the competition between barley and different weed species in a controlled environment in relation to selective weed control

C. Gée<sup>1\*</sup>, E.A Veron Zarate<sup>1</sup>, A. Matějicek<sup>1</sup>, E. Denimal<sup>2</sup> and B. Chauvel<sup>1</sup>

<sup>1</sup>Agroécologie, INRAE, Institut Agro, Univ. Bourgogne, Univ. Bourgogne Franche-Comté, F-21000 Dijon, France

<sup>2</sup>Institut Agro, Cellule d'appui à la recherche en science des données, 26 Bd Dr Petitjean, 21000 Dijon, France

\* [christelle.gee@agrosupdijon.fr](mailto:christelle.gee@agrosupdijon.fr)

### Abstract

The application of a site-specific herbicide is an effective way to contribute to environmental conservation. More can be done by also preserving biodiversity to control only highly competitive weeds that represent a minority of the varieties. In this study, the potential of visible imagery is evaluated to define the competitive ability of two categories of weeds, common and segetal, in the presence of a spring barley crop. Working in a controlled environment and two competitiveness traits, plant cover deduced from visible images and height, were estimated. Then, the competitive strategies for light were identified using the relative competitive performance index (RCP) for these two traits. A ranking according to their competitive power is proposed and compared to the literature. The results reveal that some segetal species such as *Bromus secalinus* showed a higher competitive ability than the common species in mesocosm's conditions.

**Keywords:** weed, competition, barley, RGB image, proximal sensing, mesocosm

### Introduction

Weeds have always been considered as harmful plants to crop development, as their presence in the crop site can significantly reduce yield. Their destruction is most often based on the application of site-specific herbicides by using variable rate spraying applications, this allows for local weed control while minimizing the use of chemical inputs. These systems use camera technologies involving the implementation of artificial intelligence techniques to discriminate between crop and weed, and identify certain weeds from each other (Pflanz et al. 2018; Peña et al., 2013). However, only a small percentage of weeds cause significant crop losses (Albrecht, 2003) and currently some of these species suffer from a strong decline in abundance (Fried et al., 2009). There are no operational systems based on image acquisition that allow the selectivity of weeds according to their competitive power. Thus, in a context of biodiversity preservation, it is necessary to identify weeds with high competitive ability and destroy them, which would allow the preservation of the other weeds that are less competitive and that are becoming rare (in abundance) and locally have been classified as threatened (Cirujeda et al., 2011). Among weeds, there are the common and segetal species. Unlike common weeds, segetal species are weeds of field crops whose annual cycle mimics the life cycle of the crop with which they are associated (Rotches-Ribalta et al., 2015). The hypothesis for this study was aligned to the premise that segetal species (preferentially specialist species) were going to cause lower competitive effects upon barley functional traits than common weeds (preferentially generalist species). This potential low ability to compete is one of the factors that could explain the regression of the populations of segetal species (Jauzein, 2001; Lemoine et al., 2018). The objective

was to define a ranking of the competitive response of weeds when growing with barley in order to differentiate a wide range of segetal plants and common weeds for selective weed control. This ranking was based on non-destructive measurements: natural plant height (as reference method) and plant cover deduced from visible imagery. Indeed, the plant height is considered as a main trait to characterize light competition between plant-plant (Falster and Westoby, 2003). The method based on visible images was analyzed against the results of the reference method, based on height measurements. This work analyzed the ranking results according to their competitive power and discussed their competitiveness for light.

## Materials and methods

### Field experimental site.

Experiments were held in mesocosms, under controlled conditions (soil composition and irrigation management), in the facilities of the Institut national de la recherche pour l'agriculture, l'alimentation et l'environnement (INRAE), in Dijon (coordinates: 47°19'03.5"N 5°04'19.8"E), during the development cycle of the plants from the tillering stage to the booting stage. The mesocosms were prepared in plastic boxes of 1.20m x 1m and 1.1m<sup>3</sup> of volume as dimensions (Fig. 1); these were filled with organic substrate comprising 65% of sand, 15% of clay, 10% of humus and 10% of lime without any further fertilization correction. Weed seeds (9 plants/row) were sown on March 4th and barley seeds (144 plants/m<sup>2</sup>) on March 10<sup>th</sup>, 2021. Out of the initial selection of 36 species, only 16 were analyzed, from which six were segetal species and ten were common weeds (Tab. 2). These were regarded as competitors, and a cereal crop as the target; each of the weed species selected for this experiment followed a gradient of morphological and biological characteristics intending to make a broad representation of different functional traits. The chosen cereal crop for this experiment was spring barley (*Hordeum vulgare* L. cv. RGT Planet), due to the season of experimentation and seed material availability. The seeding rate was the same for all plants. Each weed species was randomly assigned to a mesocosm, without replicates. Each mesocosm was divided into three study areas (Fig.1): one quarter was dedicated to the growth of barley alone (Zone 1, Z1), another quarter was dedicated to the weed alone (Zone 4, Z4) and half was a mixture of barley and weeds (Zone2 and Zone3, Z2&Z3, also named competition zone).

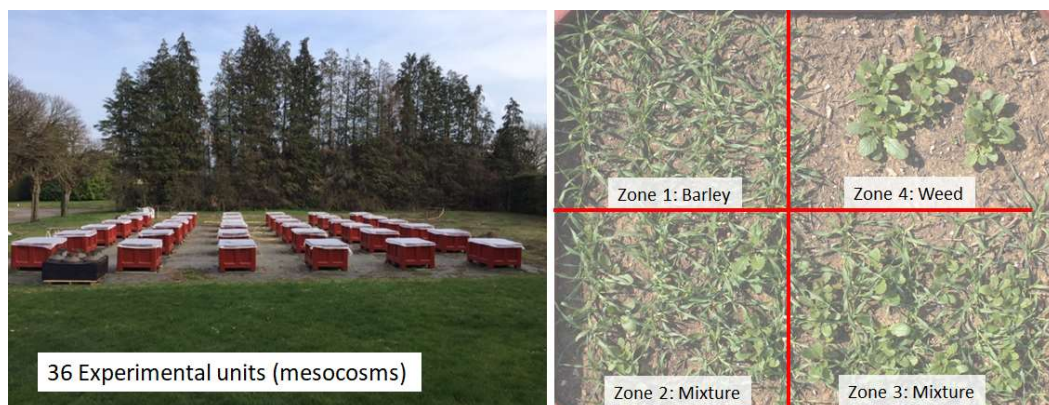


Figure 1. Illustration of the mesocosms experiment (left). Description of the arrangement of seedlings in a mesocosm (right).

### Data collection.

Non-destructive measurements of competition parameters were carried out in on five dates, within March to May 2021 (13<sup>th</sup> April; 20<sup>th</sup> April; 23<sup>th</sup> April; 30<sup>th</sup> April and 3<sup>rd</sup> May). Photographs were taken at 2m above the mesocosms using a Canon EOS 470D camera (Fig. 2). Image analysis was done using homemade software (developed from Matlab; [Gée et al., 2021](#)) that delivered the percentage of plant cover (i.e. crop, weed or crop & weed) in the different zones taking into account a central safe zone (SZ) of the image in order to avoid any border effect to the analysis (Fig. 3). The natural height was also measured within the same period in which the photos were taken with the help of a simple ruler scale, measured in centimeters, taking the measure from the stem's base, going upwards to the highest point of the plant, whether this was a leaf or the stem; each measurement was done on different plants.

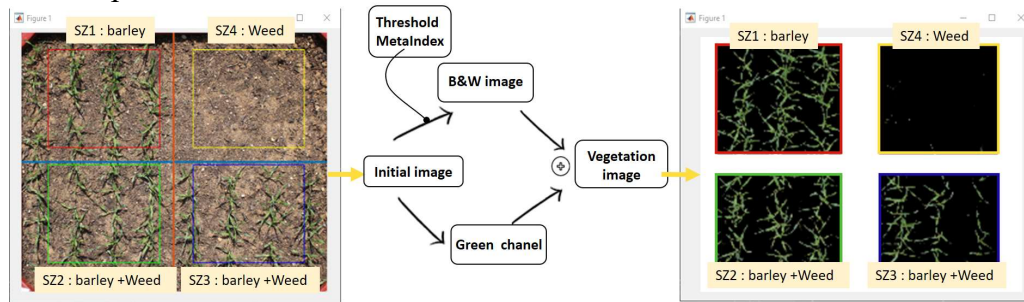


Figure 3. Illustration of the image processing to calculate the percentage of plant cover in the different safe zones (Z1: barley control zone, Z2&Z3: mixture zone and Z4: weed control zone)

Ranking weeds relative competitive performance. In the first analysis of the first stages of development, height (cm) and plant cover of the crop were assessed to infer the competitive effect for light acquisition of weeds on barley growth. The values used in this analysis were the mean height per mesocosms per sampling date. For this, the relative growth rate (RGR) was selected as the descriptor parameter, and calculated from each zone of mesocosm. RGR was determined by using the following the equation ([Evans 1972](#)):

$$RGR = \frac{\ln(P_{n+1}) - \ln(P_n)}{t_{n+1} - t_n} \quad (1)$$

where,  $P$  is the observed parameter of the object under study, i.e. the height (cm) of barley and the plant cover (%) of barley&weeds;  $P_{n+1}$  is the parameter measured at time  $(n + 1)$ ,  $P_n$  at time  $n$  and  $t_{n+1} - t_n$  is the change in time. Among the five sampling dates, the date 2 and date 3 were selected to calculate the RGR.

To assess competitive relationships between species inside each mesocosms, the relative competitive performance (RCP) proposed by [Keddy et al. \(2002\)](#) was used. The values obtained in each variable and per mesocosm were pooled before conducting the analysis. The RCP formula, Eq. (2), was adapted to obtain negative values if the RGR in the competition zone led to a decrease compared to the RGR obtained in the control zone, while positive values indicate an increase.

$$RCP = \left( \frac{RGR_{comp} - RGR_{cont}}{RGR_{cont}} \right) * 100 \quad (2)$$

where,  $RGR_{comp}$  and  $RGR_{cont}$  are the RGR in the competition zone, considering the average of  $RGR_{SZ2}$  and  $RGR_{SZ3}$  and the RGR in the control zone, considering the average  $RGR_{SZ1}$ .

### Statistical analysis.

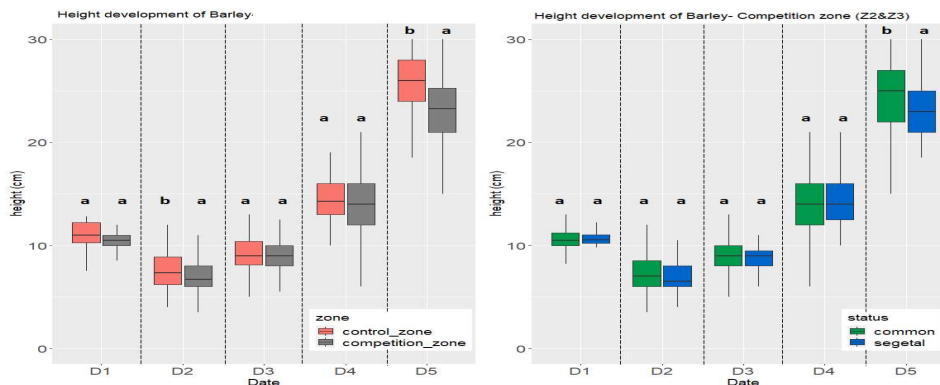
To assess competition between crop and weeds, an analysis of variance (ANOVA) was performed to test the significant effect of the factors "zone" (control vs. competition zone) and "status" (common vs. segetal) on height, and on canopy cover. Tukey's multiple comparison procedure was then applied to compare the means for each factor. The goal was to test the following hypothesis: (H0) there are no differences in terms of height (or plant cover) between the zone (or status). A p-value of 0.05 was applied. Statistical analyses were performed in the R environment for statistical computing, using R version 4.0.3 (R Core Team, 2020) and RStudio (RStudio Team, 2020), an integrated development environment for R.

## Results and Discussion

### Temporal height evolution.

Figure 4 (Panel A) depicts the progressive increase in natural height of the barley studied in this experiment in the different zones during the five dates of sampling. The development of the crop height is less important in the competition zone (Z2&Z3) than in the control zone (Z1), indicating an interaction effect. Between the dates D1 and D2, a normal decrease of the barley height is explained because the plant leaf has finished its growth and starts to droop. In the competition zone, a more precise analysis shows that barley height development is similar regardless of the type of weeds present, except for the last date. In addition, barley height distribution in the competition zone (Z2&Z3) seems to show a greater dispersion in common plant mesocosms. A statistical significant effect of the zone factor is observed on the dates D2 and D5 (p-value<0.05). Concerning height of weeds (Fig. 4 Panel B), the height is higher in the competition zone (Z2&Z3) than in the control zone (Z4) which indicates a statistical significant competition effect (Fig. 4 Panel B) according to the Tukey-test. In addition, in the competitive zone, the dispersion of the height measurement is significant higher for segetal weeds, half composed of monocots (thin leaf) and eudicots (broad leaf) while the common ones are mainly composed of eudicots (Tab. 1). It should also be noted that the weed height is much lower than that of the barley, especially on the last sampling dates.

A.



B.

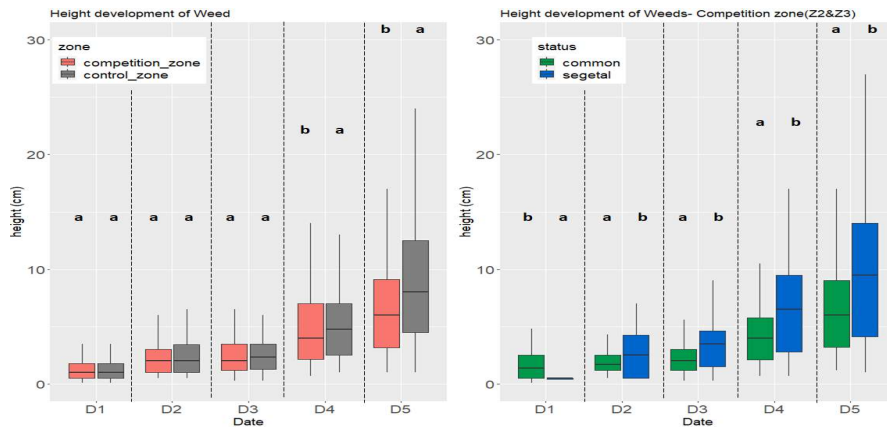


Figure 4. Height development of barley (Panel A) and weeds (Panel B) in different conditions in both zones (left), inside the competition zone (right), through sampling dates. Letters are results of Tukey's post-hoc test for means comparison ( $p$ -value threshold of 0.05). Means with the same letters are not significantly different.

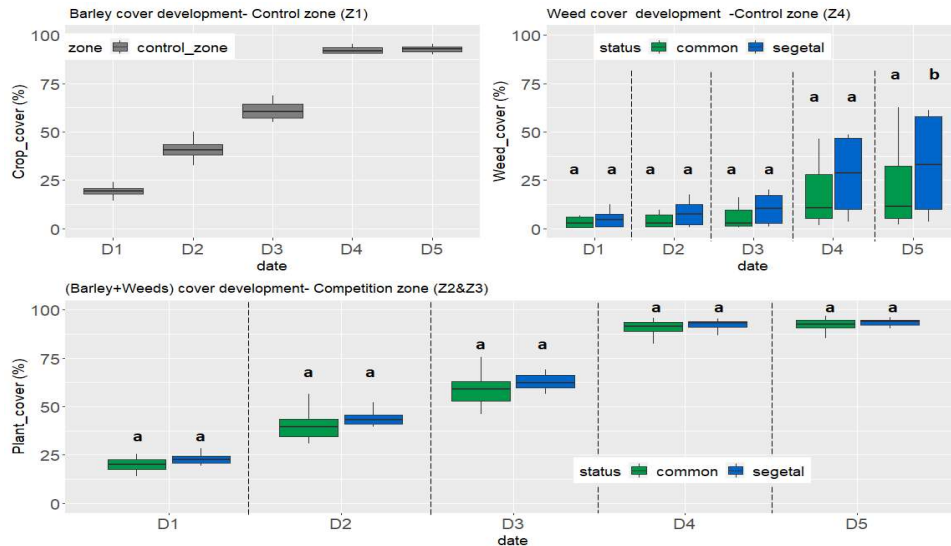


Figure 5. Plant cover evolution for each zone of mesocosms. Temporal evolution of barley cover in SZ1 (top left), of weed cover in SZ4 (top right) and the mixture in SZ2&SZ3 (bottom). Letters are results of Tukey's post-hoc test for means comparison ( $p < 0.05$ ). Means with the same letters are not significantly different.

#### Temporal plant cover evolution.

Figure 5 shows the overall evolution of the vegetation cover in each zone for each mesocosm. For zone 1, the control zone for barley (SZ1), the evolution is such that a saturation of the image is observed for the dates D4 and D5 (Fig 5. top left). Regarding weed control (Fig 5. top right), weed cover for both, segetal and common weeds, shows a high dispersion over time with a statistical significant difference of weed cover among the status factor for the last date D5. In particular, the segetal species show a higher dispersion of plant cover due to a greater diversity of plant leaves. The competition zone (SZ2&SZ3) represents all the plant covers, barley and weeds, with no significant difference according Tukey-test. Finally, over time, it should be noted that weed coverage is lower than that of barley.

### Ranking the RCP values (%) deduced from RGR of crop height and plant cover.

The RCP calculations were done between Date 2 and Date 3 considering a normal growth of height and avoiding saturation effect observed in images. Firstly, Figure 6 presents the results of the RGR of vegetation cover (barley+weed) as a function of the safe zone for each mesocosm. Concerning the RGR of weeds in the central safe zone (SZ4), the production of leaf is low for CARHY, AGOGI, LAMPU, ALOMY and GERDI and very high for ANTAL, SINAR, AVEFA and LACSE. This observation is a translation of the growth cycle of each weed and thus an indirect information on its competition strategy for light. For barley, the RGR in SZ1 is globally similar in all mesocosms where the value is the highest for the AGOGI mesocosm. In the competition Zone (SZ2&SZ3), the RGR reflects the overall stand cover (barley + weed). On all mesocosms, the crop height RGR is always positive, which seems to indicate that no experimental effects (saturation or important leaf overlay) is observed. Then, the RGR values of (SZ1+SZ4) were compared with the ones of SZ2&SZ3 to analyze the competitive performance; this is the role of the RCP. A positive value of RCP indicated a potentially stronger competition for height positioning as explained by different authors (Didon, 2002; Denelle et al., 2020). The ranking of the RCP results was first examined based on the height of the culture, with the image data completing the analysis (Table 2). The increase in RGR of the crop height in the competition zone with BUPRO or BROSE indicated that these species caused a higher pressure on height development, hence the positive RCP values for crop height. Only these two segetal species suggest a potentially high competitiveness for height positioning; results also confirmed with RCP of plant cover. The RCP of crop height was negative in front of 66% of the segetal species analyzed. When in mixture with CENCY, AGOGI, AVEFA and ALOMY, the RCP values obtained indicate that crop height RGR was slower in relation with the control. Among these segetal species, only ALOMY has a positive value of the RCP of plant cover RGR, the others having a negative value. Although better interpretations could've been suggested with more types of data gathered in this experiment, the negative height RGR of barley in front of certain weed species can be expected to be related to the conclusions of Nagashima and Hikosaka (2011). Their experience suggest that neighboring plants regulate their height positioning depending of their surrounding competitors in order to avoid extra biomass and height development that can be detrimental for the plant's survival in time. However, for AVEFA and ALOMY these results are in conflict with the literature, which considers that they have a high pressure on cereal crops (Mamarot and Rodriguez, 2014).

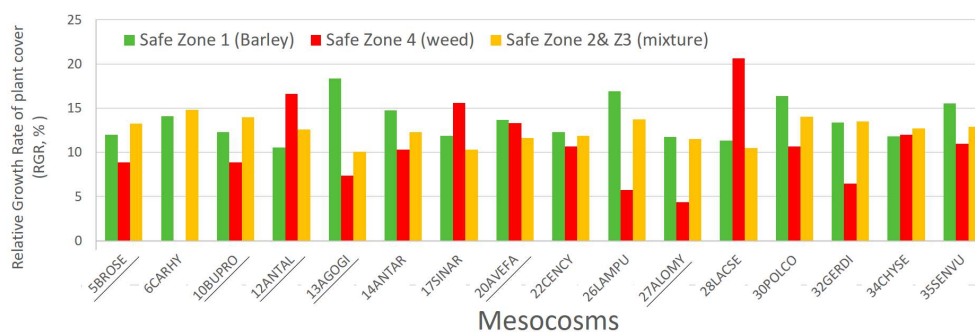


Figure 6: Comparison of the relative growth rate (RGR) of plant cover in each zone (SZ1, SZ4 and SZ2&SZ3) of each mesocosm (Mesocosm N°EPP0 code).

Table 2. List of the total weed species and EPPO code (European and Mediterranean Plant Protection Organization) used in the mesocosms experiment. RCP ranking, from lower to higher competitive performance, of crop height relative growth rate (RGR) with the associated value of plant cover RGR (and the rank) in the mixture zone. Columns indicate EPPO code, status and RCP in % and rank.

EPPO Code	Status	Scientific name	Type	RCP(%) of the crop height RGR	rank	RCP(%) of plant cover RGR	rank	
ANTAR	Common	<i>Anthemis sp.</i>	Eudicot	26.03	1	-9.80	10	
<b>BUPRO</b>	<b>Segetal</b>	<b><i>Bupleurum rotundifolium</i></b>	<b>Eudicot</b>	<b>25.04</b>	<b>2</b>	<b>14.20</b>	<b>2</b>	High competitiveness
SINAR	Common	<i>Sinapis arvensis</i>	Eudicot	22.76	3	-22.93	15	RCP>0
LAMPU	Common	<i>Lamium purpureum</i>	Eudicot	10.85	4	-14.43	11	
ANTAL	Common	<i>Cota altissima</i>	Eudicot	10.28	5	8.02	3	Low competitiveness
CARHY	Common	<i>Cardamine hirsuta</i>	Eudicot	7.62	6	6.73	5	RCP<0
LACSE	Common	<i>Lactuca serriola</i>	Eudicot	6.8	7	-19.14	14	
<b>BROSE</b>	<b>Segetal</b>	<b><i>Bromus secalinus</i></b>	<b>Monocot</b>	<b>5.49</b>	<b>8</b>	<b>15.49</b>	<b>1</b>	
CENCY	Segetal	<i>Cyanus segetum</i>	Eudicot	-1.16	9	-0.23	8	
AGOGI	Segetal	<i>Agrostemma githago</i>	Eudicot	-1.42	10	-33.57	16	
ALOMY	Segetal	<i>Alopecurus myosuroides</i>	Monocot	-2.06	11	1.41	7	
SENVU	Common	<i>Senecio vulgaris</i>	Eudicot	-3.63	12	-14.81	13	
<b>AVEFA</b>	<b>Segetal</b>	<b><i>Avena fatua</i></b>	<b>Monocot</b>	<b>-5.43</b>	<b>13</b>	<b>-14.53</b>	<b>12</b>	
GERDI	Common	<i>Geranium dissectum</i>	Eudicot	-8.55	14	4.71	6	
CHYSE	Common	<i>Glebionis segetum</i>	Eudicot	-23.05	15	7.70	4	
POLCO	Common	<i>Fallopia convolvulus</i>	Eudicot	-23.45	16	-9.31	9	

## Conclusion

Through non-destructive measurements (height and plant cover), this study explored the complex competition relationships between different weed species (segetal and common) with barley crop. The hypothesis that segetal species are less competitive than common weeds in mixture with cereal crops could be challenged as, in this experiment, some segetal species (BROSE and BUPRO) proved to be similar or even more competitive than common weed species. Despite the difficulties encountered by the experimental design (weed emergence) and the image processing not allowing discriminating between crop and weeds in the competition zone, the analysis of a gradient of response by populations and the ranking of these responses according to the results obtained under controlled conditions remains a valid idea. Thus, the competitiveness of a large number of species can be assessed simply by using mesocosms as experimental units. It would then be possible to detect plants with low competitive capacity in real time using the cameras in the spot-spraying systems so as not to destroy them and maintain a certain level of floristic diversity in the cultivated fields without reducing yields.

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