

# Effects of competition on compensation point and phenological development in *Sonchus arvensis* L.

*Varwi Jacob Tavaziva*



## **Effects of competition on compensation point and phenological development in *Sonchus arvensis* L.**

Effekter av konkurrens på kompensationspunkt och fenologisk utveckling hos åkermolke (*Sonchus arvensis* L.)

*Varwi Jacob Tavaziva*

**Supervisor:** Associate Prof. Dr. Anneli Lundkvist, Swedish University of Agricultural Sciences, Department of Crop Production Ecology

**Co-Supervisors:** Professor Dr. Theo Verwijst, Swedish University of Agricultural Sciences, Department of Crop Production Ecology

Dr. Johannes Forkman, Swedish University of Agricultural Sciences, Department of Crop Production Ecology

**Examiner:** Professor Dr. Henrik Eckersten, Swedish University of Agricultural Sciences, Department of Crop Production Ecology

**Course title:** Independent Project / Master thesis in Biology

**Course code:** EX0565

**Credits:** 30 hec

**Level:** Advanced level, A2E

**Program:** Experimental Plant Biology, Master's Program

**Place of publication:** Uppsala

**Year of publication:** 2012

**Picture on the cover:** Varwi Jacob Tavaziva

**Online publication:** <http://stud.epsilon.slu.se>

**Key words:** below ground biomass, *Hordeum vulgare* L., organic farming, perennial sow-thistle, perennial weed, regenerative structure, Scandinavia, spring barley, weed control

**Sveriges lantbruksuniversitet**  
**Swedish University of Agricultural Sciences**

Faculty of Natural Resources and Agricultural Sciences  
Department of Crop Production Ecology

## Abstract

*Sonchus arvensis* L. is a perennial weed which has become more common in Scandinavian countries owing mainly to the proliferation of organic farming which limits the use of herbicides. When soil tillage is used for controlling perennial weeds, farmers are usually recommended that mechanical disturbance should be done at the developmental stage when the plant is most sensitive for disturbance which coincides with minimum below ground dry weight. Håkansson (1969b) has shown that *S. arvensis* reaches its minimum dry weight of underground regenerative structures at 5-7 true leaves. The time taken to reach dry weight minimum depends on environmental factors like temperature but may also be influenced by competition from other plants. The aim of the study was to evaluate if the phenological stage, at which minimum dry weight of below ground biomass occurred in *S. arvensis* (i.e. compensation point), was affected by competition from a crop. A greenhouse box experiment was performed at Ultuna, close to Uppsala, Sweden (59° 48'N, 17°39'E) during January - April 2012. The plant material used in the experiment was *Sonchus arvensis* L. (perennial sow-thistle) and *Hordeum vulgare* L. var Judit (spring barley). The experiment consisted of two treatments: *S. arvensis* grown (1) with (C+) and (2) without (C-) competition from spring barley. The compensation point in competing plants occurred at leaf stages 4 and 5, while it occurred at the 4 leaf stage in plants without competition. For given phenological stages, weight loss of below-ground structures did not differ between the C+ and C- plants, apart from the 5 leaf stage, at which the C+ plants had lost more in weight than the C- plants. The initially planted root parts of C+ plants lost more weight than the C- plants. Phenological development of *S. arvensis*, in terms of development of numbers of leaves over time, was delayed by competition with spring barley. For agronomy practice, these results imply that *S. arvensis* should be controlled earlier than previously was recommended, and that competition from a crop can be used in addition to greatly deplete the below-ground resources in *S. arvensis*.

**Keywords:** below ground biomass, *Hordeum vulgare* L., organic farming, perennial sow-thistle, perennial weed, regenerative structure, Scandinavia, spring barley, weed control.



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# 1 Introduction

*Sonchus arvensis* L. (perennial sow-thistle) is a weed that is prevalent throughout most of the temperate regions of the world (Holm et al., 1997) (Figure 1). It is considered to be a troublesome weed in Swedish agricultural systems especially in organic farming (Håkansson, 1969). *S. arvensis* is thought to have originated in Europe and later spread to new areas such as the western part of Asia (Lemna and Messersmith, 1990). It is a species which is classified as important among the perennial weeds because of its unique vegetative reproductive system (Håkansson, 1969). It has a fast growing reproductive system which reproduces by roots and seed and is also deep-rooted with the whole plant filled with milky latex (Lemna and Messersmith, 1990). It is a C<sub>3</sub> plant and is adapted to various soil types but mostly the neutral or slightly alkaline soils meaning that it does not do well in highly acidic soils (Lemna and Messersmith, 1990). The leaves are mainly found on the lower section of the stem and it develops rosettes at an early stage of growth, thereby increasing the photosynthetic area of the plant. The flowers are perfect and pollination is via insects such as honeybees and blister beetles (Pegtel, 1973). According to Håkansson and Wallgren, 1972, the plant does not flower in the first year but if it develops under favourable conditions with respect to light and nutrition then it will easily flower.

*S. arvensis* develops new roots and sprouts shoots in late April (Håkansson and Wallgren, 1972). Most of the shoots develop from within 10 cm of the upper surface of the soil (Lemna and Messersmith, 1990). Håkansson (1969) states that emergence from deeper soil layers is also possible. Seedlings grow slowly initially but after the second week when leaves are 3-5cm long, growth begins to peak and the roots will spread rapidly to new areas (Chepil, 1946). The roots begin to thicken when *S. arvensis* plants have 5-7 leaves and at this juncture the plant is considered to have reached its compensation point i.e. the minimum level of root reserves (Vanhala, 2006). The thickening of the roots continues up until mid-

summer (Lemna and Messersmith, 1990). The plant begins to flower at the 12-leaf stage and this is usually in the month of July (Håkansson, 1969). Thereafter the plant will produce seeds and in autumn the reproductive system will enter a period of innate dormancy (Håkansson and Wallgren, 1972). This period is triggered by above-ground shoot senescence and a decreasing day length (Henson, 1969). The underground roots store their food reserves as carbohydrates, and inulin is the major storage carbohydrate (Lemna and Messersmith, 1990). *S. arvensis* can be used as a livestock feed and is considered to be highly nutritious for rabbits (Szcza-wenski and Turner, 1978). Boulos (1973) states that *S. arvensis* roots can be used as a coffee substitute when roasted. It is also rich in pentacyclic triterpenes and therefore has the potential to become an important crop in the pharmaceutical industry (Lemna and Messersmith, 1990).



Figure 1. Distribution of *Sonchus arvensis* L. across the world (Holm et al., 1997).

Recently *S. arvensis* has become more common in Scandinavian countries owing mainly to the proliferation of organic farming which limits the use of herbicides (Anbari et al., 2011). Another valid reason might be due to the competitive traits exhibited by the plant which are; its ability to reproduce either by roots or seeds, high and efficient acquisition of nitrogen (Eckersten et al., 2010; 2011), which is limiting in spring under Swedish conditions (Eckersten et al., 2010), fast growing and deep rooted system which can increase the strength of shoot competition by masking the adverse effects of competition for light (Cahill, 2002), relative innate



dormancy in autumn which means that it is difficult to induce the plants to deplete their food reserves via new growth by means of soil tillage during this period (Håkansson, 1969), seeds do not require light for germination to occur (Lemna and Messersmith, 1990).

*Sonchus arvensis* causes economic losses by reducing crop yield especially in cereals, increased costs for purchasing herbicides and land degradation due to increased soil tillage. It has been observed to be an overwintering host for potato virus N (Lemna and Messersmith, 1990). There are currently various methods which are being employed in order to curb the continued proliferation of *S. arvensis* which ranges from cultural, mechanical to chemical methods. Anbari et al (2011), mentions that the most effective control of *S. arvensis* should be devised in a way that depletes the roots' food reserves and also restrict production and dispersal of achenes. *S. arvensis* is susceptible to mechanical disturbance by burial and defoliation (Håkansson and Wallgren, 1972). Based on this, soil tillage, which mimics burial and mowing (defoliation) are currently being used as effective control methods. The vegetatively growing roots of *S. arvensis* are mainly found in the top 10-15 cm of the soil and thus burying the roots below the above-mentioned depth will greatly reduce the viability of the creeping roots (Vanhala, 2006). Soil tillage also reduces root viability through fragmentation. Anbari et al (2011) concluded that larger root fragments are more viable than smaller ones. However, tillage in autumn is thought to have less effect on *S. arvensis* because at this time of the season, it undergoes innate dormancy (Håkansson, 1969). According to Vanhala (2006), the most efficient mechanical method for controlling *S. arvensis* is bare fallowing. It is more efficient if started in autumn (Lemna and Messersmith, 1990). This strategy has its own limitation in that it is an expensive method with respect to lost yield during the fallowing period and labour demands. Mowing is another mechanical control strategy which can be maximized so as to counteract biomass production. Due to the palatability of *S. arvensis*, grazing can also be used as a way of limiting biomass production (Anbari et al., 2011). In general, *S. arvensis* is partially resistant to a wide range of common broadleaf herbicides (Fogelfors and Lundkvist, 2008). May and Smith (1977) noted that *S. arvensis* shoots sprout late in the spring and thus they escape early herbicidal treatment of crops. Nevertheless, *S. arvensis* is highly prone to herbicides such as diuron and atrazine (Lemna and Messersmith, 1990). A combination of the above-mentioned control strategies is currently being employed in the control of *S. arvensis*. However Vanhala (2006) points out that even though there are several control strategies of *S. arvensis*, there is no single control strategy which is suitable for all agricultural

systems. It is against this back drop that it is imperative to further refine and improve the current control methods.

When soil tillage is used for controlling perennial weeds, farmers are usually recommended that mechanical disturbance should be done at the developmental stage when the plant is most sensitive for disturbance which coincides with minimum below ground dry weight. Håkansson (1969b) has shown that *S. arvensis* reaches its minimum dry weight of underground regenerative structures at 5-7 true leaves while the phenological stages for minimum dry weight were 4-7 leaves for *Cirsium arvense* (L.) Scop (Dock Gustavsson, 1997) and 3-4 leaves for *Elytrigia repens* (L.) Desv. ex Nevski (Håkansson, 1967; 1969a). The time taken to reach dry weight minimum depends on environmental factors like temperature but may also be influenced by competition from other plants. In the above mentioned studies, the defined stages for minimum dry weight were performed without competition.

The aim of the study was therefore to evaluate if the phenological stage, at which minimum dry weight of below ground biomass occurred in *S. arvensis* (i.e. compensation point), was affected by competition from a crop. The first hypothesis is that the compensation point in competing plants (C+) occurs at a later phenological stage, compared to plants without competition (C-). The second hypothesis is that the below-ground structures at the compensation point will have lost more in weight for the C+ plants, compared to the C- plants. The third hypothesis is that the initial root parts of C+ plants will lose more weight than the C- plants. The final hypothesis is that phenological development, in terms of numbers of leaves, over time will be slower for C+ plants, compared to the C- plants.

## 2 Materials and methods

A greenhouse box experiment was performed at Ultuna, close to Uppsala, Sweden (59° 48'N, 17°39'E) during January - April 2012. The plant material used in the experiment was *Sonchus arvensis* L. (perennial sow-thistle) and *Hordeum vulgare* L. var Judit (spring barley).

### 2.1 Root preparation of *Sonchus arvensis*

Root runners of *S. arvensis* used in the experiment were initially collected in the fall of 2005 from organically grown short-term grasslands with cereals in the rotation at Sala, Sweden (59° 40'N, 16° 40'E). They were then planted in buckets filled with soil and a plant bank was established from the above-mentioned material. The root runners were stored over winters in buckets with a soil volume of  $10^{-2} \text{ m}^3$ , from October until June in a dark cold store room at +2 to +4°C. In June roots were replanted, fertilized with about 70 kg N/ha early in the season and grown outdoors in the same type of buckets during June to October 2006-2011. The soil in the buckets was kept moist during the whole growing seasons.

On 26 January, 2012, buckets were retrieved from the cold room and the roots were washed to remove the soil. The roots were cut into small fragments with weight as the determining factor. Each root fragment had a standardized weight of approximately 1.5 g. In total about 190 root fragments were prepared.

Twenty root fragments were randomly sampled from the batch for (i) determination of the ratio between dry weight and fresh weight and (ii) studies whether root length was a function of the number of shoots produced. Length and fresh weight of the sampled root fragments were measured. The root parts were dried at 60°C to constant weight and the dry weight of each root was measured.

For the main experiment, 162 root fragments were randomly selected and length and fresh weight of each root was measured and recorded.

## 2.2 Spring barley

To study emergence time and rate of germination of two different varieties of spring barley: Ingrid (Weibulls, Sweden) and Judit (SW Seed, Sweden), a test experiment was conducted in January 2012. Four pots were filled with soil and the varieties were planted in two pots each (20 seeds per pot). Judit emerged after 5 days with 100 % emergence whilst Ingrid did not emerge at all. Based on these findings, it was concluded that Judit was going to be used for the box experiment.

## 2.3 Planting

Before planting, 162 small boxes (17 cm × 12 cm × 14 cm) were filled with soil and irrigated. The soil consisted of 85% organic matter (moderately decomposed peat), 15% sand and a nutrient content of about 1 g N per box and NPK proportion of 2:1:2.

Planting of *S. arvensis* was done on 27 January 2012. In each box, one *S. arvensis* root was planted at the center of the box at a depth of 3 cm. The shoots started to emerge 5 days after planting (DAP). Watering was then done soon after the planting. Spring barley seeds were sown 7 days (1 February) after *S. arvensis* had been planted when the emergence rate of *S. arvensis* had reached 46%. Barley was planted in 81 boxes at a depth of 3 cm. The seeding rate was 400 seeds m<sup>-2</sup>, which translated to 18 seeds per box. Barley seedlings emerged after approximately 4 days (5 February).

In total, 162 boxes were planted out of which 144 boxes were designated for the main experiment. Spare boxes were used if there was no emergence of *S. arvensis* in the boxes from the original design.

## 2.4 Experimental design and randomization procedure

The experiment consisted of two treatments: *S. arvensis* grown (1) with and (2) without competition from spring barley. Six blocks were established in the green house and each block contained a randomized C– plot (*S. arvensis* without competition) and a C+ plot (*S. arvensis* with competition) (Figure 2). Each C– plot contained 12 C– boxes, and each C+ plot contained 12 C+ boxes. This gave in total 6 blocks × 2 plots × 12 boxes = 144 boxes. For each block, two slopes were derived, one for each treatment.

| <b>C- plot:</b>                        |    |    | <b>C+ plot:</b>                     |    |   |
|--|----|----|-------------------------------------|----|---|
| <i>S. arvensis</i> without competition |    |    | <i>S. arvensis</i> with competition |    |   |
| 4                                      | 7  | 6  | 12                                  | 1  | 9 |
| 1                                      | 12 | 10 | 4                                   | 11 | 8 |
| 11                                     | 8  | 5  | 3                                   | 7  | 2 |
| 2                                      | 3  | 7  | 10                                  | 6  | 5 |

Figure 2. An example of the design of one block in the experiment. Each block consisted of a randomized C- plot (*S. arvensis* without competition) and a C+ plot (*S. arvensis* with competition). Each plot contained 12 randomized boxes.

Twelve harvests were performed in the experiment strictly following the phenological developmental stage of *S. arvensis* (from emergence to 11 leaf stage). A stage was considered to be reached when the largest shoot per root had reached that stage (Table 1).

In advance, it was determined which boxes (6 C+ and 6 C-) should be harvested at what phenological stage. The boxes of the main experiment were randomly assigned a number from 1 to 144 and a randomization exercise was conducted to determine which box number was to be harvested at each phenological stage/harvest occasion. Below follows a brief description of how the exercise was done:

1. First, 144 pieces of paper was numbered 1-144 (to mimic the number of boxes we had in the experiment).
2. Twelve pieces of the papers were put in 12 different aluminum trays (to mimic the different plots in the experiment). The pieces were counted from 1 upwards which meant that the first aluminum tray had numbers 1 to 12.
3. Two aluminum foils (plots) represented 1 block, thus the first block had two trays with numbers 1 to 24.
4. Numbers 1 to 12 represented the first treatment whilst 13 to 24 represented the other treatment.
5. The aluminum trays were then set up just as the experiment was set up in the greenhouse i.e. into 6 blocks.
6. For the first harvest, one piece of paper was randomly picked with a number from each block to come up with 12 pieces of paper for each harvest. This procedure was continued until 'harvest number 12'.

7. Then 6 papers were picked from the different blocks and assigned to the C+ treatment. Again 6 papers were picked from the different blocks and assigned to the C- treatment (these represent the first harvest). This was repeated until ‘harvest number 12’.

Table 1. Phenological stage of *Sonchus arvensis* at each harvest occasion

| Harvest occasion | Phenological stage of <i>Sonchus arvensis</i> |
|------------------|---|
| 1                | 1 = Emergence                                 |
| 2                | 2 = 2 leaf stage                              |
| 3                | 3 = 3 leaf stage                              |
| 4                | 4 = 4 leaf stage                              |
| 5                | 5 = 5 leaf stage                              |
| 6                | 6 = 6 leaf stage                              |
| 7                | 7 = 7 leaf stage                              |
| 8                | 8 = 8 leaf stage                              |
| 9                | 9 = 9 leaf stage                              |
| 10               | 10 = 10 leaf stage                            |
| 11               | 11 = 11 leaf stage                            |
| 12               | 12 = 12 leaf stage                            |

## 2.5 Fertilization and watering

The plants were fertilized on 8 February 2012, 12 DAP *S. arvensis*. The fertilizer solution consisted of a mixture of 49 liters of water and 1 liter of concentrated nutrient solution (Blomstra, Cederroth International AB, Falun, Sweden). After calculations, the rate of 60 kg N/ha translated to 0.27 liters of the above-mentioned mixture, was added to each box. The boxes were watered during the experimental period not to limit growth.

## 2.6 Greenhouse conditions

The green house had lamps to mimic day light. The light intensity of the lamps was measured by a light measurement device (Skye instrument SKP220). The mean light intensity at 100 cm height above the green house table was 1.2  $\mu\text{mol m}^{-2}$

$2 \text{ s}^{-1}$ . The temperature was regulated throughout the day: 4 am to 10 pm: +18°C, 10 pm to 4 am: +10°C.

## 2.7 Sampling procedure – *Sonchus arvensis*

Harvesting was done with respect to phenological development following the results of the randomization exercise. The first harvest was done just as the first *S. arvensis* shoot had broken the soil surface. At all harvests, the *S. arvensis* plants were partitioned into the following components: above-ground shoots (leaves, stem), below-ground shoot, old root and fine roots. The samples were then dried in the oven at +60°C for a period of 24 hours. The dry weight of each sample was measured and recorded. Since the boxes had been chosen for a particular phenological development stage, they were not harvested on the same day but harvested when the plant had reached the prescribed phenological stage. Therefore, the date of each harvest was recorded. No measurements were recorded for spring barley.

Harvest 2 (second phenological stage) was conducted when the *S. arvensis* had reached the two-leaf stage. At this stage and the subsequent stages, a leaf was considered to be `fully developed` when it had reached 5 cm in length. The boxes which had a much delayed emergence or no emergence at all of *S. arvensis* were replaced with spare boxes. The same harvesting procedure was used for the later harvests.

On day 17, the boxes were re-arranged within their blocks to bring them closer to the light source because the barley shoots were bending towards the light source. Harvesting was continued until *S. arvensis* had reached the 12-leaf stage. In a number of boxes, *S. arvensis* started to produce flowers at the 9 and 10 leaf-stages. It was then decided to harvest the boxes when they had started to produce flowers regardless of the fact that they had not reached the prescribed phenological development stage or not. This was done because flower development meant that there was not going to be further primary leaf development. Boxes that had not reached the prescribed phenological development stage were excluded from the further analysis. At each prescribed phenological development stage, photographs were taken (Figures 3-6). The experiment was terminated on day 66 (3 April).

a. C+, developmental stage 1.



b. C-, developmental stage 1.



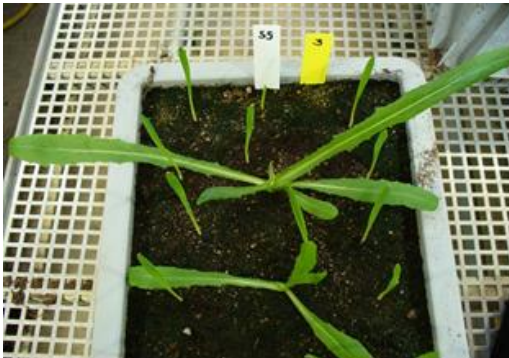
c. C+, developmental stage 2.



d. C-, developmental stage 2.



e. C+, developmental stage 3.



f. C-, developmental stage 3.



Figure 3. Photographs depicting the phenological developmental stages 1-3 under competition (C+) (a, c, e) and non-competition (C-) (b, d, f) treatments of *S. arvensis*.



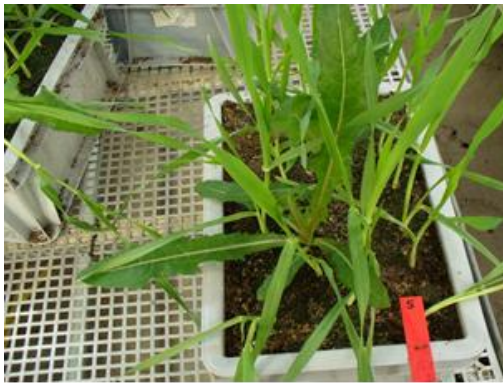
a. C+, developmental stage 4.



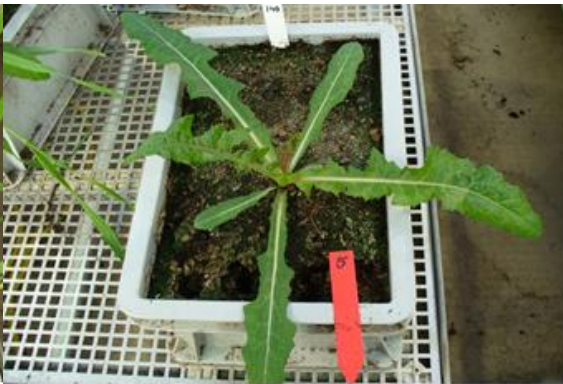
b. C-, developmental stage 4.



c. C+, developmental stage 5.



e. C-, developmental stage 5.



e. C+, developmental stage 6.



f. C-, developmental stage 6.



Figure 4. Photographs depicting the phenological developmental stages 4-6 under competition (C+) (a, c, e) and non-competition (C-) (b, d, e) treatments of *S. arvensis*.

a. C+, developmental stage 7.



b. C-, developmental stage 7.



c. C+, developmental stage 8.



d. C-, developmental stage 8.



e. C+, developmental stage 9.



f. C-, developmental stage 9.



Figure 5. Photographs depicting the phenological developmental stages 7-9 under competition (C+) (a, c, e) and non-competition (C-) (b, d, e) treatments of *S. arvensis*.

a. C+, developmental stage 10.



b. C-, developmental stage 10.



c. C+, developmental stage 11.



d. C-, developmental stage 11.



Figure 6. Photographs depicting the phenological developmental stages 10-11 under competition (C+) (a, c) and non-competition (C-) (b, d) treatments of *S. arvensis*.

## 2.8 Statistical analyses

In the statistical analyses described below, the distribution of dry matter values of below-ground plant parts and old roots (residual vs. predicted) were plotted and observations were transformed to logarithm, to stabilize the variance. The Kruskal-Wallis test was applied.

The effects of treatment on dry matter values of below-ground plant parts and old roots at each phenological stage were evaluated in a mixed model (Procure Mixed) (SAS Institute Inc., 2002-2004) containing the main factors treatment and

block. Least squares means of dry matter values of below-ground plant parts and old root were separated by the option PDIFF, i.e. all possible probability values for the hypothesis  $H_0: LSM(i)=LSM(j)$ .

The effects of treatment and phenological stages on % dry matter depletion of old roots were evaluated in a mixed model containing the main factors treatment, phenological stage and block. Least squares means of % dry matter depletion of old roots were separated by the option PDIFF, i.e. all possible probability values for the hypothesis  $H_0: LSM(i)=LSM(j)$ .

To estimate the average number of days it took to reach a certain number of leaves at the two treatments, data was analysed by a linear regression model:  $Day=a+b \times Phenology$ , where Day is the number of days it took to reach a certain number of leaves. This was done for each treatment and each of the blocks, to give 2 x 6 slopes. The average slope values for each treatment were then compared.

## 3 Results

### 3.1 The compensation point based on minimum below ground dry weight

The dry weight of the below ground structures of *S. arvensis* decreased gradually during the early phenological stages, reached a minimum, and then increased again during further phenological development, in both the treatments without (Figure 7a) and with competition (Figure 7b). For the treatment without competition, the minimum weight was attained at the four-leaf stage and weight was significantly higher at the five-leaf stage (Figure 8a). For the treatment with competition, minimum weight also was reached at the four-leaf stage, and maintained at the five-leaf stage (F-test:  $p=0.21$ ). The weight at the six-leaf stage was significantly higher than the weight of the two previous stages (Figure 8b). Statistical analyses comparing effects of treatments at each phenological stage showed a significant lower below-ground dry weight of *S. arvensis* at five and six leaf-stages in treatments with competition compared with treatments where *S. arvensis* was grown alone.

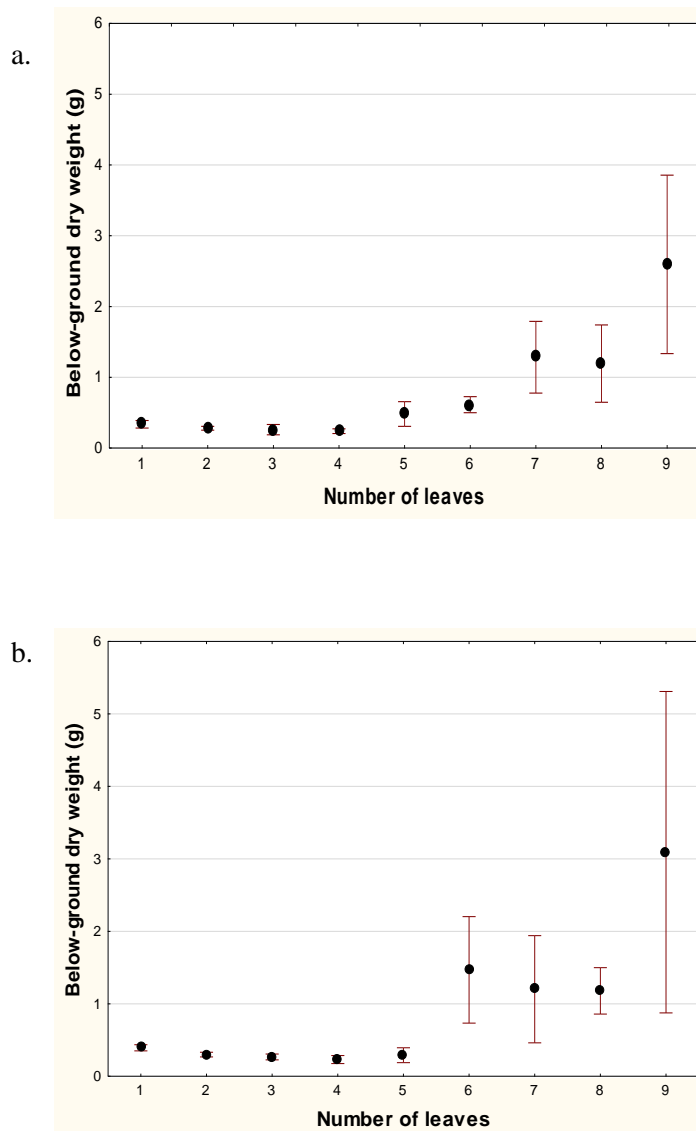
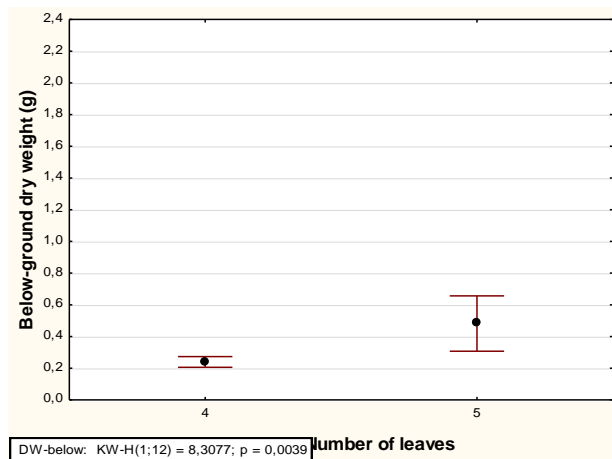


Figure 7. (a) Dry weight of below ground structures ( $\text{g plant}^{-1}$ ) against phenology for the non-competition treatment (C-). (b) Dry weight of below ground structures ( $\text{g plant}^{-1}$ ) against phenology for the competition treatment (C+). Means and 95% confidence intervals are given.

a.



b.

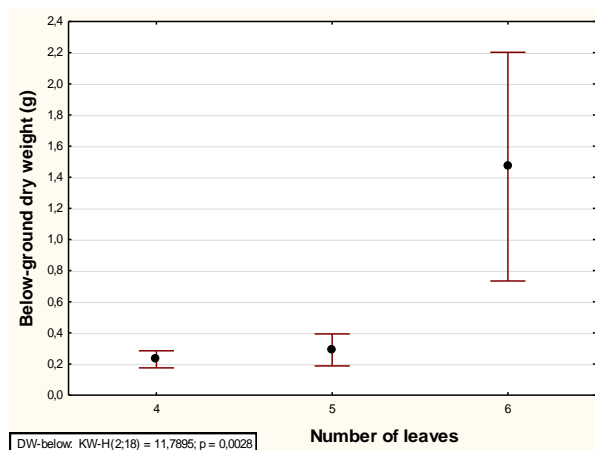


Figure 8. (a) Dry weight of the below ground system ( $\text{g plant}^{-1}$ ) at phenology stages 4 and 5 (non-competition treatment). (b) Dry weight of the below ground system ( $\text{g plant}^{-1}$ ) at phenology stages 4, 5 and 6 (competition treatment). Kruskal-Wallis test was applied for both figures.

### 3.2 Degree of depletion of the below ground structures

For a given phenological stage, the dry weight of the below ground structures of *S. arvensis* did not differ between the C- and C+ treatments, apart for phenology 5: For example, dry weight at the 5-leaf stage in C- equals 0.482 g, while it equaled 0.29 g for the C+ treatment, see Figure 9.

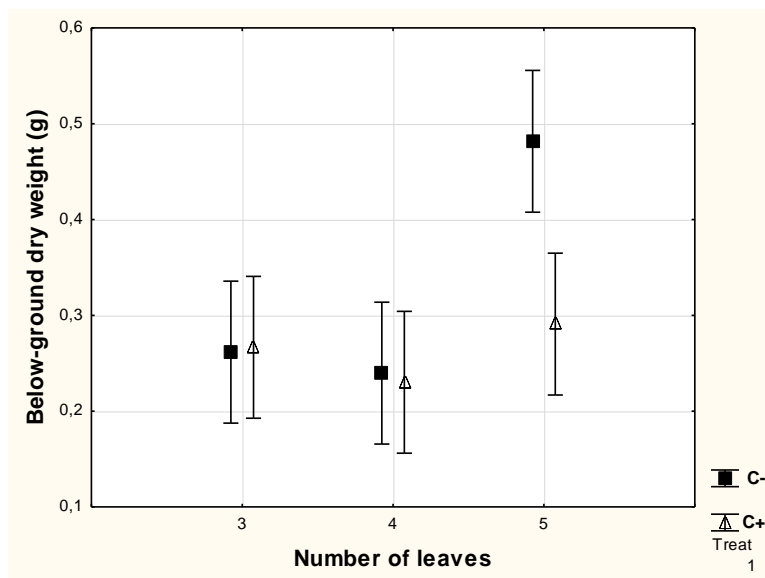


Figure 9. Dry weight of the below ground system ( $\text{g plant}^{-1}$ ) at phenology stages 3 - 5 for the C+ and C-treatments. Vertical bars denote 95% confidence intervals.

### 3.3 The compensation point based on total plant dry weight

On total plant dry weight basis, both C- and C+ plants already had attained a significant weight increase at the four-leaf-stage, indicating that the compensation point at whole-plant basis was reached at the three-leaf-stage or earlier (Figures 10a, b).



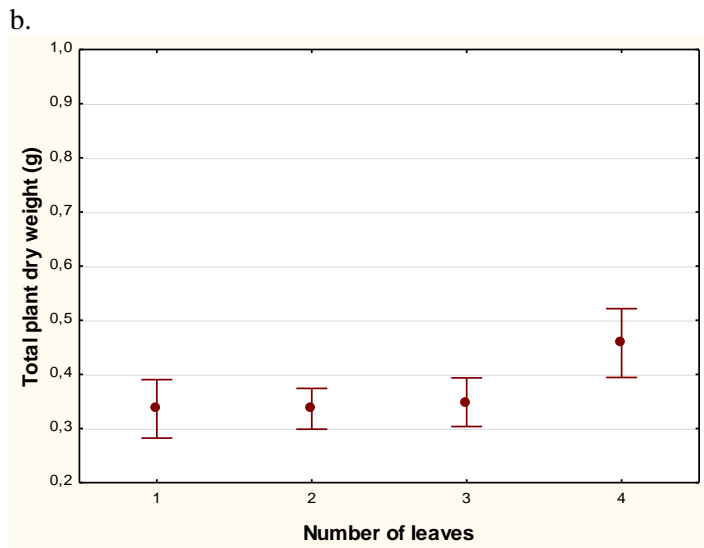
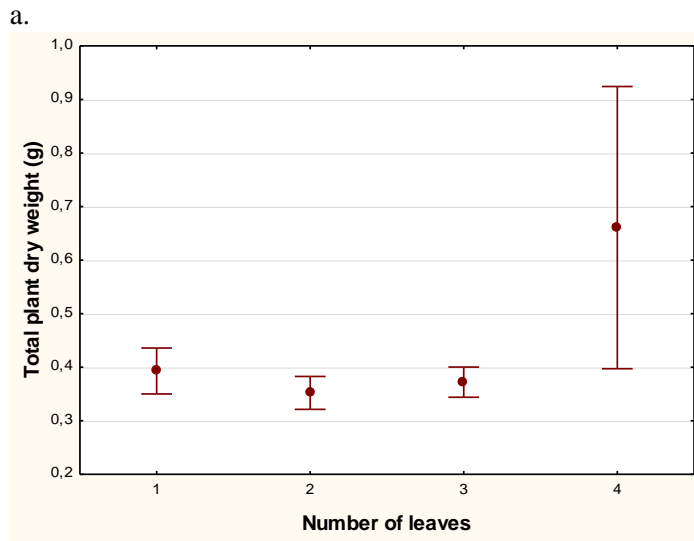


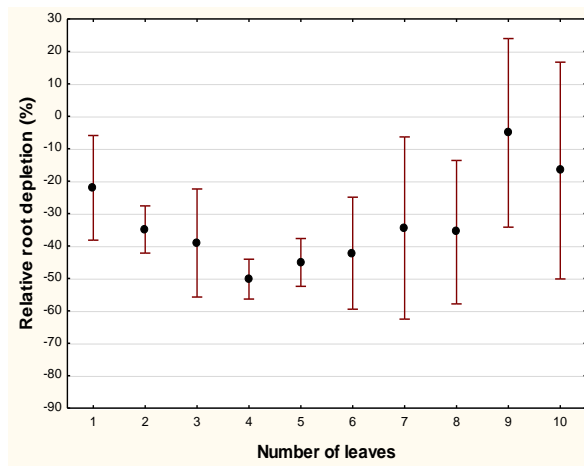
Figure 10. (a) Dry weight of the total plant ( $\text{g plant}^{-1}$ ) at phenology stages 1-4 (non-competition treatment). (b) Dry weight of the total plant ( $\text{g plant}^{-1}$ ) at phenology stages 1-4 (competition treatment).

### 3.4 Depletion and regrowth of the old root part

The initially planted root fragments which had a fresh weight of 1.477 g (SE = 0.007) had a dry matter content of 26.3%, giving a dry weight at planting of 0.388

g. These root parts then lost weight, which can be expressed as a relative depletion ( $100 \times (DW_{init} - DW_{act})/DW_{init}$ ), where  $DW_{init}$  is the dry weight at planting and  $DW_{act}$  the dry weight at a given phenological stage. This is shown in Figures 11a, and 11b, for the C- and C+ plants respectively.

a.



b.

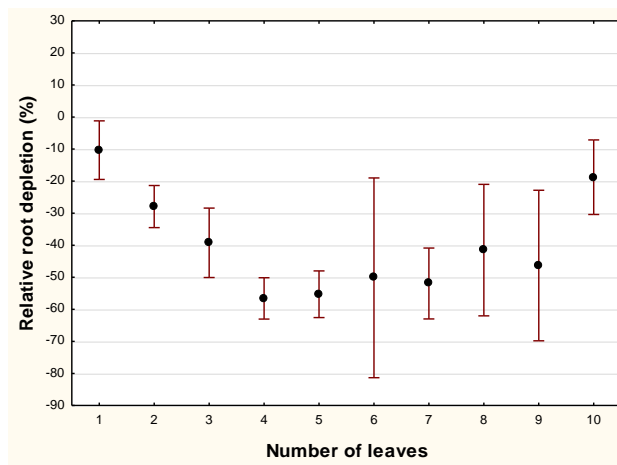


Figure 11. (a) Relative root depletion and regrowth (%) of old root part at phenology stages 1-10 (Non-competition treatment). (b) Relative root depletion and regrowth (%) of old root part at phenology stages 1-10 (Competition treatment).

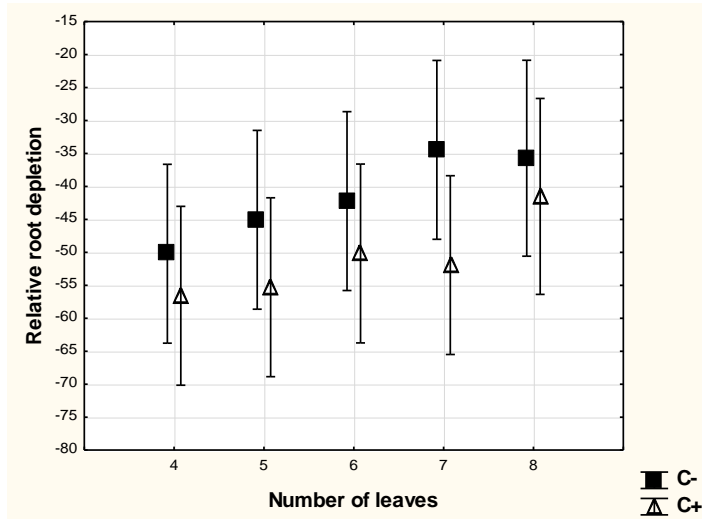


Figure 12. Relative root depletion of *S. arvensis* at leaf-stages 4-8 with (C+) and without (C-) competition. Depletion is more profound for the C+ plants than for the C- plants. Vertical bars denote 95% confidence intervals.

For the C- plants, relative root depletion seems to succeed less profound (not exceeding 50% of their initial weight) than for the C+ plants. Regrowth also proceeded faster with phenology in the C- plants: At later phenological stages (9-10), the relative loss for C- plants did not differ from zero (Figure 11a), while the C+ plants still had a significant negative increment (Figure 11b). At all phenological stages, relative root depletion was significantly lower for the C- plants, compared to the C+ plants (Figure 12).

### 3.5 Phenological development over time

As harvest was performed at a predetermined phenological stage, the time it takes to reach a certain number of leaves can be depicted as a function of phenology which is done for the C- and C+ plants in Figures 13a and 13b respectively.

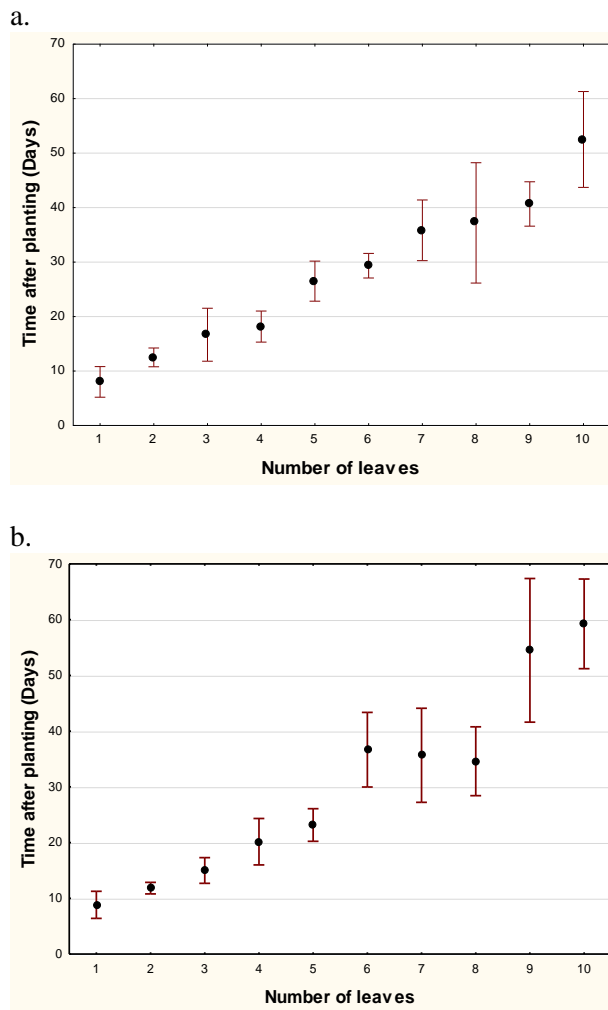


Figure 13. (a) Phenological development over time (non-competition treatment). (b) Phenological development over time (competition treatment).

By combining the data in a linear regression model:  $\text{Day} = a + b \times \text{Phenology}$ , where day is the number of days it took to reach a certain number of leaves. This was done for each treatment and each of the blocks, to give 2 x 6 slopes. The average slope values for each treatment were then compared; it was shown that the relation between real time and phenological development differed between the C- and C+ plants (Figure 14). It takes more days to advance from a lower to a higher phenological stage for C+ plants compared to C- plants. In other words, phenological development of *S. arvensis* is slower under competitive pressure.

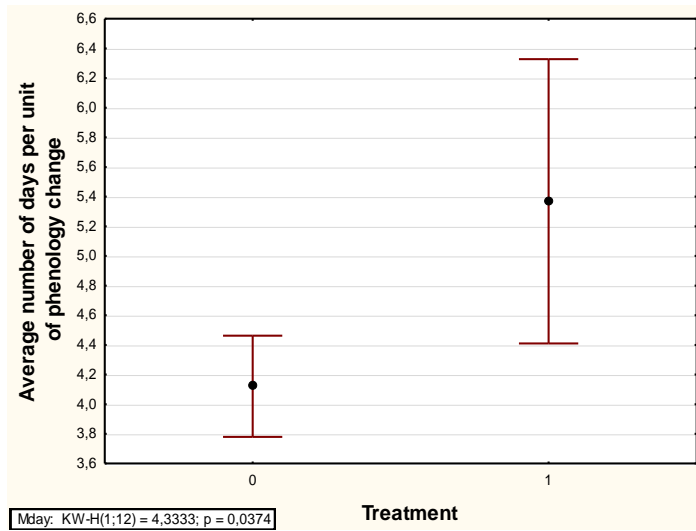


Figure 14. Slope (average number of days per unit of phenology change), for treatments 0 (C-) and 1 (C+).

## 4 Discussion

### 4.1 Compensation point (Below ground system)

For *S. arvensis* subjected to competition, an absolute minimum dry weight of the below-ground structures was reached in our experiment at phenology 4 or 5 whilst for *S. arvensis* with no competition, the absolute minimum dry weight was reached at phenology 4 (Figures 7a, b). *Sonchus arvensis* and spring barley emerged simultaneously in the C+ treatment, which means that at least competition for light had not been extensive in the early phenological stages. This may explain why the compensation point was reached at about the same phenological stage, regardless of treatment. This is also substantiated by the dry weights of the below-ground system, which did not differ between the C+ and C- treatments at three- and four leaf stages (Figure 9). However, gain in weight was already higher in the C- treatment at leaf stage 5, indicating that inter-specific competition for light was occurring between spring barley and *S. arvensis* at this stage. The initial loss in weight of the below ground structures can be attributed to the allocation of stored food reserves to above ground plant parts and also to respiration of the old root and developing fine roots (Lemna and Messersmith, 1990). This also is in line with conclusions by Håkansson (1969a), who asserts that the initial loss in dry weight in underground parts is attributed to development of new roots and shoots. The stage of minimum below-ground weight represents the compensation point and it probably also represents a period of minimum capacity for regeneration (Håkansson, 1969b). Therefore this is the best or suitable period for mechanical control (soil tillage) of *S. arvensis* so as to stop photosynthesis earlier and impede the translocation of assimilates to the regenerative organs (Håkansson, 2003). However, in our experiment, the compensation point in both treatments occurred at a slightly earlier phenological stage (4 to 5) than found by Håkansson (1969b), who recorded

that *S. arvensis* reached its absolute minimum dry weight of underground regenerative structures at 5-7 true leaves. It should be noted though, that our experiment was carried out under sub-optimal conditions as it was winter time and so I had a problems with low light intensity. Nevertheless, we managed to capture the compensation point using artificial lighting from lamps. Just after the compensation point has been reached there is a sudden and significant increase in below-ground biomass (see Figures 8a, b). This increase is due to the fact that the allocation of photosynthesized carbon to the below-ground structures is now greater than the sum of their respiratory losses and allocation to above ground plant parts. This causes a development of new roots, which are beginning to thicken, and results in an increase in dry weight. These observations tally with Håkansson`s (1969) experiment in which he found out that, when the below-ground system has surpassed the absolute minimum dry weight, there is a sudden and fast increase in weight. He attributes this to net photosynthesis becoming positive and therefore there is re-translocation of assimilates back into the root system from the above-ground photosynthesizing shoots. This in turn leads to an increased regenerative capacity of the below-ground system, thereby making mechanical control difficult to implement at this period. At later phenological stages (7-8), the dry weight of the below ground structures is relatively constant. This is likely due to the fact that the plants were about to flower and therefore more assimilates were being channeled to the above-ground system so as to initiate flower and seed production as this is regarded as an energy demanding process. This assertion is supported by the fact that most boxes began flowering at phenology stages 8 and 9. This observation is further supported by Lemna and Messersmith (1990), who mention that *S. arvensis* undergoes another period of low regenerative capacity, after the compensation point, when the above-ground shoots elongate and flower stalks begin to develop.

#### 4.2 Compensation point (Total plant biomass)

Basing on the total plant dry weight, both C+ and C- plants reached the compensation point earlier, at the three leaf stage or earlier (Figures 10a, b). The logical explanation for this is that, when also the weight of the above-ground system is considered, the outflow of assimilates to the above-ground system from the root was now considered to be part of the system. As a result we observe an early compensation point as compared to compensation point based on the below-ground system.

### 4.3 Analyses of old root dry weight

There is a significantly larger depletion of the old root under competition at and after the compensation point (see Figure 12). At the compensation point, *S. arvensis* which had been subjected to competition with spring barley, had less food reserves as compared to the plants with no competition. A probable explanation for this observation is that *S. arvensis* had started to compete for light with spring barley, therefore there might have been much more demand for assimilates from the root system leading to an increased depletion. The high demand for assimilates was to cater for biomass allocation to the above ground shoots so as to capture more light for photosynthesis. Vanhala et al. (2006), asserts that young plants are much more sensitive to competition for light. Further support comes from Zollinger and Kells (1991); they found out that the more *S. arvensis* plants are subjected to light competition, the less they are able to accumulate assimilates in roots. Conceiving the above ground parts then as a source of carbohydrate for the below ground system, one also can say that the source function of the C+ was weakened by competition for light. For the C- treatment, the above-ground parts functioned as a source, and at leaf stage 9 and 10, the old roots were replenished and their weight equaled initial weight again, while the weight of the old roots of the C+ treatment still was below the initial weight.

### 4.4 Relation between phenology and real time

It takes more days to advance from a lower to a higher phenological stage for C+ plants compared to C- plants. The reason for this might be attributed to the competitive pressure exerted by spring barley on *S. arvensis*, which in turn caused a reduction in growth rate. There was also another interesting visual observation; the C- plants flowered earlier than the C+ plants. This finding can be used to further refine mechanical control strategies of *S. arvensis*.



## Conclusions

I conclude that *S. arvensis* should be controlled earlier (at 4 to 5 leaf stage) than previously was recommended, and that competition from a crop can be used in addition to utterly deplete the below-ground resources in *S. arvensis*. It should be noted also that this experiment has to be repeated under natural conditions so as to substantiate the results.

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## Acknowledgement

I would like to take this opportunity to gratefully thank my supervisor, Anneli Lundkvist, for the support and guidance she provided throughout my thesis. I am also deeply indebted to my co-supervisors, Theo Verwijst and Johannes Forkman. I want to thank them for the support and advice they provided.