Crop Protection 104 (2018) 11–20

Contents lists available at ScienceDirect

Crop Protection

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

Explanations for *Amaranthus retroflexus* growth suppression by cover crops

Aurélie Gfeller[a], Juan Manuel Herrera[b], Frederic Tschuy[a], Judith Wirth[a,*]

[a] Agroscope, Herbology in Field Crops and Viticulture, Plant-Production Systems, Switzerland
[b] Agroscope, Varieties and Production Techniques, Plants and Plant Products, Switzerland

ARTICLE INFO

Keywords:
Allelopathy
Cover crops
Root exudates
Shading
Weed suppression

ABSTRACT

This work studies the factors responsible for amaranth (*Amaranthus retroflexus*) growth suppression by different cover crops (CC). In field trials with two shading levels amaranth biomass was similar, demonstrating that light interception by CC was not the primary mechanism responsible for amaranth growth suppression. We could show that below a threshold of 3 t/ha of CC biomass, amaranth growth suppression was negatively correlated with CC biomass ($R^2 = 0.41$) and that this correlation was influenced by the CC species. Brassicaceae and black oat (*Avena strigosa*) did not follow this relation and effectively controlled amaranth even with a low biomass. The effects of root interactions between amaranth and CC on amaranth growth were further tested in the absence of competition for light, water and nutrients under controlled conditions. We could show that phacelia (*Phacelia tanacetifolia*) had no growth repressive effect, whereas buckwheat (*Fagopyrum esculentum*), black oat and forage radish (*Raphanus sativus* var. longipinnatus) significantly suppressed amaranth growth by 46, 37 and 49% through indirect root interactions and by 68, 41 and 62% through direct root interactions. We deduce that this was due to allelopathic root exudates. We conclude that in order to describe and predict the weed suppressive ability of CC it is not sufficient to only study biomass production and shading.

1. Introduction

Due to new pesticide regulations in Europe that create strong incentives for growers to limit herbicide applications (Melander et al., 2013), minimizing or even avoiding the use of synthetic herbicides has gained interest in weed management research. Therefore, system-oriented approaches to weed management that make better use of alternative tactics are being developed. One approach is the use of species with strong weed-suppressing ability as a component of integrated crop management (Lemessa and Wakjira, 2015). Cover crops (CC) provide multiple ecosystem benefits, including reducing soil erosion, improving the soil physical environment, managing nutrients, weed suppression etc. (Blanco-Canqui et al., 2015). They suppress weeds through direct competition for resources such as light, nutrients, water and space and indirectly by chemical means (Blanco-Canqui et al., 2015).

The effect of CC biomass and subsequent shading on weed suppression has been studied extensively in field trials and is often considered as the main factor of weed suppression (Brennan and Smith, 2005; Finney et al., 2016; Lemessa and Wakjira, 2015; Wittwer et al., 2017). Moreover, it could be shown that a high above ground competitiveness of CC is necessary to effectively inhibit weed growth through shading (Brust et al., 2014; Uchino et al., 2011). In contrast, little is known of the contribution of allelopathy in weed control by CC as most research in this area fails to effectively demonstrate allelopathic effects (Duke, 2015). A better understanding of CC-weed interactions and allelopathic effects for different CC species is needed (Blanco-Canqui et al., 2015) and it is a prerequisite to successfully utilizing CC for weed control. Suppressing weeds by utilizing the allelopathic phenomenon is included among the most important innovative weed control methods (Jabran et al., 2015). However, if allelopathy occurs, separating it from competition effects is challenging as allelopathy in the field is generally subtle and not easily teased out from competition (Duke, 2015). Under field conditions allelopathy does not occur independently of other mechanisms of plant interference, and this outcome is the combined effect of allelopathy and competition (Belz, 2007).

Previously we have demonstrated that amaranth (*Amaranthus retroflexus* L.) growth suppression by buckwheat (*Fagopyrum esculentum* Moench) was due to both competitive shading effects and root interactions of a potentially allelopathic nature (Falquet et al., 2014). Amaranth as a typical summer annual broadleaf weed was chosen for further research. Consequently, in this study, our objective was to understand how amaranth growth is suppressed by different annual CC in the field and to verify whether successful amaranth suppression is largely dependent on CC biomass and shading or whether allelopathic root interactions are implicated.

In field trials we could show that shading was not the principal

* Corresponding author. Agroscope, Herbology in Field Crops and Viticulture, Route de Duillier 50, Case Postale 1012, Nyon 1, Switzerland.
E-mail address: judith.wirth@agroscope.admin.ch (J. Wirth).

http://dx.doi.org/10.1016/j.cropro.2017.10.006
Received 22 June 2017; Received in revised form 5 October 2017; Accepted 9 October 2017

growth suppressive factor and we could not find strong indications for allelopathy in field soil. In parallel, we selected four CC from the field for studying allelopathic root interactions under controlled conditions. We concentrated on root interactions as plant roots, a metabolically active hotspot in the soil, take an essential part in below-ground interactions and the major route by which allelochemicals reach the surrounding soil is through root exudation (Massalha et al., 2017). Moreover, the biochemical interactions occurring in the rhizosphere are the least well characterized in all of the biotic zones studied (Latif et al., 2017).

Our hypotheses were (1) that additionally to light competition other growth repressive factors occur and (2) that CC strongly suppressing amaranth growth independently of shading produce allelopathic root exudates. The questions we wanted to answer were (1) is amaranth growth negatively correlated with CC biomass? (2) is shading the primary mechanism of amaranth growth suppression by CC? and (3) can we infer that the observed growth suppressive effects are due to allelopathy?

2. Materials and methods

2.1. Experimental field sites and plant material used

Two field experiments were performed in 2014 and 2015 on adjacent trial sites with a loamy soil (sand 30%, clay 25%, silt 46%, pH 6.6) at Agroscope in Changins, Switzerland (46°24′E, 06°13′N; 445 m a.s.l.). Weather data were obtained from the agrometeo website (http://www.agrometeo.ch/wmeteo) for the weather station Changins. Amaranth seeds were purchased from Herbiseed (Twyford, England) and 13 different frost sensitive winter annual CC commonly used in Switzerland representing a diversity of plant families were purchased from OH semences and Fenaco (Switzerland) (Table 1).

2.2. Experimental setup of the field trials

The experiments were designed as a randomized split plot design. In 2014, the effects of two factors on amaranth growth were determined. The first factor CC species was applied at the plot level, comprising 13 different CC species and the control (no CC) (Table 1). The second factor shading was applied at the subplot level, comprising high and low shading. In 2015, nitrogen (N) was added at planting in order to increase CC biomass and study whether this had an effect on amaranth suppression. Consequently, three factors were studied (CC species, shading and N fertilization). A similar randomized split design was used in a complete block design with 2 levels. One block was fertilized with 109 kg N per ha, the other block received no fertilization. The plot factor CC species had 5 levels (buckwheat, black oat, forage radish, phacelia and control). The subplot factor shading was the same as in 2014.

After field preparation with a rotary harrow, CC were sown in rows with a distance of 12.5 cm and a depth of 2 cm with a common drilling machine according to their specific seeding rates on the 7th of August in 2014 and on the 30th of July in 2015. The latter was done after ploughing because of high density of cereals volunteers (Table 1). Amaranth was sown by hand in the small sowing areas on the same dates (Fig. 1). However, due to very dry weather in 2015, the germination of amaranth was very low and it was consequently re-sown on the 7th of August. Each CC was grown in four 24 m^2 plots. Eight plots in 2014 and six plots in 2015 were left with bare soil (control) respectively. In the centre of each plot, two subplots of 1 m^2 each were established (Fig. 1):

- Subplot 1 (high shading) was used to study amaranth growth under the CC canopy representing normal growth conditions in an undisturbed stand.
- Subplot 2 (low shading) was used to study amaranth growth under low shading conditions between the nets.

In the centre of each subplot, four small sowing areas (0.01 m^2 each) in one line in a CC inter-row were defined with 15 cm separation between each sowing area. In each sowing area, 120 amaranth seeds were sown by hand. Seeds were subsequently covered with fine soil. In order to insure high amaranth pressure, around 1200 amaranth seeds were sown within the subplots (outside of the central inter-rows) in the four neighbouring inter-rows. In subplots 2, a pair of facing nets (1.2 m × 0.5 m) with a 1 cm mesh was placed in the central CC inter-row 11 days after sowing of amaranth (DASA) to push aside the CC canopies and reduce shading on amaranth plants, attempting to eliminate the effect of competition for light. At 18 DASA in 2014 and at 14 DASA in 2015, the number of amaranth plants was reduced to 5 and 3 respectively in each sowing area. Due to low germination in 2015, 3 plants were left instead of 5. Throughout the experiments all other weeds were removed by hand within the subplots. No fertilizer was applied during the trial in 2014. On the 31st of July 2015, 0 and 109 kg ha^{-1} (as 27.5% ammonium nitrate) were applied.

2.3. Field sampling

2.3.1. Plant material for dry weight determination

Amaranth plants of two sowing areas per subplot were harvested at two consecutive dates: 28 and 55 DASA in 2014 and 31 and 55 DASA in 2015. Additionally, aboveground plant material was sampled in all plots by destructive harvest in two 0.25 m^2 quadrats at 56 DASA in 2014 and 62 DASA in 2015 (Fig. 1). Plant material was separated into CC and weeds and dried at 50 °C for 5 days in order to determine dry weight (DW).

Table 1
List of CC species used in the field trials in 2014 (all species listed) and in 2015 (the first four species listed). The latin name of the species, the common name, the name of the variety, the name of the family and recommended seeding rates are indicated.

Latin name	Common name	Variety	Family	Seeding rate (kg ha^{-1})
Fagopyrum esculentum Moench	buckwheat	Lileja	Polygonaceae	75
Avena strigosa Schreb.	black oat	Pratex	Poaceae	100.2
Raphanus sativus var. *longipinnatus* L.H. Bailey	forage radish	Structurator	Brassicaceae	14.5
Phacelia tanacetifolia Benth.	phacelia		Boraginaceae	11.2
*Brassica rapa*subsp. *Pekinensis* (Lour.) Hanelt	chinese cabbage	Jupiter	Brassicaceae	20
Raphanus sativus L. var. *oleiformis* Pers.	oilseed radish	Siletta-Nova Bento	Brassicaceae	29.9
Brassica juncea (L.) Czern.	brown mustard	Vitasso	Brassicaceae	10.6
Camelina sativa (L.) Crantz	camelina	Camélior	Brassicaceae	4
Lotus corniculatus L.	birdsfoot trefoil	Léo	Fabaceae	3
Pisum sativum L. subsp. *sativum* var. *arvense* (L.)	field pea		Fabaceae	205.2
Lens nigricans (M.Bieb.) Godr.	lens	Lentifx	Fabaceae	52.7
Sorghum bicolor (L.) Moench x *Sorghum sudanense* (Piper) Stapf	sorghum sudangrass	BMR 201	Poaceae	31.5
Guizotia abyssinica (L.f.) Cass.	niger		Asteraceae	9.9