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Interference potential of buckwheat, fababean, oilseed hemp, vetch, white lupine and caraway to control couch grass weed

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ABSTRACT

We evaluated the weed suppressive abilities of 6-dicotyledonous crops [buckwheat (*Fagopyrum esculentum* L), caraway (*Carum carvi* L.), faba bean (*Vicia faba* L.), oilseed hemp (*Cannabis sativa* L.), vetch (*Vicia sativa* L.) and white lupine (*Lupinus albus* L.)] in glasshouse and field experiments. In glasshouse experiment, incorporation of active charcoal between the crop and couch grass (*Elymus repens* L.) greatly reduced the inhibitory effects of buckwheat, suggesting that its allelochemicals were inhibiting the couch grass growth. Caraway and common vetch were not included in the field experiment because of their slow growth rate and formation of weed-suppressive structures in the glasshouse experiment. Then white lupin, oilseed hemp, faba bean and buckwheat were tested to investigate their weed-suppressive ability in field. Buckwheat quickly attained weed-suppressive factors [(high leaf area index (LAI) and weed-inhibitory effects of root exudates) and resulted in the lowest weed dry mass. The indeterminate growth of white lupin was important factor in its weed-suppressive ability. The most important criterion in selecting crops for weed management was the fast growth rate to form weed suppressive canopy. Rapid development of high LAI and early involvement of allelochemicals made buckwheat an ideal crop rotation for weed management. Chemicals and modes of action of buckwheat root exudates need to be revealed in future to assist in developing new herbicides.

Keywords: Allelopathy, allelochemicals, buckwheat, *Cannabis sativa* L., caraway, cereal monoculture, common vetch, couch grass, crop interference, faba bean, hemp, interference, root exudates, sustainability, *Vicia faba* L., *Vicia sativa* L., weed management, white lupin

INTRODUCTION

Weeds are major yield limiting factors in cropping systems (9). Between 1960 and 2000, global pesticide production tripled to 0.8×10^9 to 2.0×10^9 tons. The extensive use of pesticides is harmful to environment and their effect has been minimised due to development of pesticide-resistant biotypes (17,24,27). To provide food, feed, fibre and fuel in the long-term to growing human population, crop production must increase the sustainability with minimum environmental impact (27) by reduced use of pesticides with innovative choices complementing with existing management practices (28) e.g. use of

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weed smothering crops. Plant interference has two components: (i). Physical competition for growth resources (nutrients, water and light) and (ii). Allelochemicals released from the plants which are secondary metabolites. Many such secondary metabolites and their modes of action have suggested natural alternatives for weed management (17). Use of herbicides for weed control in continuous cereal cropping has negative impacts on ecosystem. Crop rotations offer the opportunity not only to replace or minimise use of present pesticides, but also to use break crops for their competitive ability and allelochemicals to suppress weeds.

Several studies have focused on identifying the improved competitive ability (CA) and allelopathic activity in cereal cultivars. Rice cultivars with allelochemical activity showed significant inhibition of different weeds (13). The FASSET crop-growth model, applied the competition between 8-winter wheat varieties and weeds for 3-years, showed that early crop development, rapid increase in height and high specific leaf area (m^2/g) were most effective components for weed suppression (22). The selection of wheat cultivars with better CA or tolerance to weeds have lower yields (15). In Canada, a survey of spring wheat cultivars suggested that better CA was at the cost of higher yield (24). In Finland, most arable land is cultivated with cereal monoculture for long time but, recently many farmers introduced some dicotyledonous crops to break the cereal monoculture to get benefits of rotational crops. Selection of break crops with improved weed-suppressive ability can provide non-chemical alternative for weed management.

Some dicotyledonous crops synthesize weed-suppressive allelochemicals e.g. buckwheat (*Fagopyrum esculentum* L.) residues effectively reduces the emergence of green pigweed (*Amaranthus powellii* L.) (12). Caraway allelochemicals (thymol, carvacol, and carvone) inhibited the germination of several weed species (*Amaranthus retroflexus* L., *Centaurea salsotitialis* L., *Raphanus raphanistrum* L., *Rumex nepalensis* Spreng., *Sinapis arvensis* L. and *Sonchus oleraceus* L. (1). White lupine (*Lupinus albus* L.) alkaloids, such as lupanine and sparteine inhibits the germination of lettuce (*Lactuca sativa* L.) (30).

Couch grass (*Elymus repens* L.) is a very competitive and very harmful persistent weed to crops in temperate regions (29). In Finland, it is most common weed and has maximum biomass accumulation in both conventional and organic farms (25). This study aimed to evaluate the ability of 6-dicotyledonous crops (buckwheat, caraway, faba bean, hemp, common vetch) and white lupin to interfere with couch grass in glasshouse and field experiments.

MATERIALS AND METHODS

The present study consisted of glasshouse experiment and field experiment. In the glasshouse experiment, the inhibition of crops on couch grass was tested. Active charcoal was incorporated into the soil to distinguish the effect of root exudates of crops. In the field experiment, the effect of crop density, relative growth rate, seed weight and leaf area index on weed growth was evaluated.

Glasshouse experiment

The Buckwheat (*Fagopyrum esculentum* L) 'local landrace', caraway (*Carum carvi* L.) cv. Sylvia, faba bean (*Vicia faba* L.) cv. Kontu, common vetch (*Vicia sativa* L.)

cv. Ebena, and white lupin (*Lupinus albus* L.) cv. Vesna as donors of possible allelochemicals were grown with couch grass as receiver in styrofoam boxes (45 × 28 × 12 cm) containing 15 kg of sandy soil. To compare the weed-suppressive ability of these crops with cereal, barley was included as a donor. Couch grass growing alone without donors was included as control. Seeds of crops and couch grass were germinated for 7-days on water agar. Seeds of oilseed hemp were infected by fungi, hence, not included in glasshouse experiment. Before transplanting seedlings, 25 g fertilizer (Garden 800G, N-P-K 17-4-25, Kekkilä Oy, Vantaa, Finland) was mixed into the soil of each box. Fourteen couch grass seedlings were transplanted in one row in the middle of each box. Ten cm from each side of the row of couch grass, a row of one of the donor crop was transplanted: 10 seedlings of buckwheat, 12 of faba bean or lupin, or 14 of barley, vetch or caraway. In another set of boxes, a trench was dug to the bottom of box and filled with mixture of 12.5 parts activated charcoal (AC, Sigma-Aldrich, C2889, Sigma-Aldrich Co. LLC.,St. Louis, US) and 1000 parts soil in a 4 cm wide band on both sides of row of couch grass (13) and then donor crops were transplanted in the same way. The boxes were placed in glasshouse [day/night temperatures of 25/18 °C and relative humidity of 40%]. High pressure sodium lamps (E40/400W, Osram Inc. München Germany) provided an 18-h photoperiod with PPFD of 340 µmol m^{-2} s^{-1} throughout the day at the top of the canopy. The experiment was conducted in a randomized complete block design with 4-replications.

Ten days after transplanting, the seedlings were thinned to 8 buckwheat, 10 faba bean or white lupin, or 12 barley, caraway or vetch. Forty two days after transplanting, the shoots of both crop and couch grass were cut from the soil surface and dried in oven at 75 °C for 4-days and weighed. Mean relative growth rate (MRGR) of crops was calculated as under (10):

$$MRGR = \frac{\ln(\mathrm{W2}) - \ln(\mathrm{W1})}{\mathrm{T2} - \mathrm{T1}}$$

Where, W2: Crop shoot dry weight (g) at time T2. W1 was recorded as 0; and T1: Transplanting Time of seedlings in box.

Field experiment

The field experiment was conducted in 2010 at the Viikki Experimental Farm, where the site was naturally infested by weeds [*Elymus repens*, *Chenopodium album*, *Capsella bursa-pastoris*, *Fallopia convolvulus*, *Fumaria officinalis*, *Lamium purpureum*, *Spergula arvensis* and *Tripleurospermum inodorum*] (60°22′ N, 24°02′ E), University of Helsinki, Finland. Buckwheat (landrace), hemp (cv. Finola), faba bean (cv. Kontu), and white lupin (cv. Vesna) were chosen due to their higher weed suppressive ability than other crops in glasshouse experiments. Oilseed hemp was added because it was not included in glasshouse experiment due to fungal contamination and its significance as an oilseed crop. Crops were sown on 17 May 2010. Seeding densities were 200 seeds/m^2 for buckwheat, 170 for oilseed hemp, 60 for faba bean, 90 for white lupin and 0 for weed fallow. Legume plots were fertilized with 20 kg N/ha (N-P-K : 16-7-13, Cemagro Oy, Lohja, Finland) and other plots with 60 kg N/ha (N-P-K : 28-3-5, Cemagro Oy, Lohja, Finland). Fertilizer was applied to seed-bed at sowing time. Plant protection was not used. The experiment was conducted in randomized complete block design with four replicates.

Plot size was 6.25 m^2 (5 x 1.25 m). Fifteen days after seeding, crop emergence in 0.25 m^2 was counted for each crop in each plot.

Plant samples were collected thrice at different growth stages: (i). First sampling (37 DAS) was at BBCH (20) growth stage GS35 when the four crops had 5 visible nodes, (ii). Second (79 DAS) was at full flowering stage (GS65) and the (iii). Third (114 DAS) at the beginning of leaf-drop (GS93). An area of 0.25 m^2 of each plot was cut at the soil surface and each sample was divided into weeds and crops, dried in an oven at 70°C for 4 d and weighed. MRGR of each sampling interval was calculated. The dry mass at the beginning was estimated by dry SSW (single seed weight) times the number of seedlings emerged 15 days after seeding in 0.25 m^2, and SSW was determined from four replicates of 25 seeds (dried at 40 °C for 48 h). Leaf area index (LAI) was measured in each plot at GS65 (15 July) with the SS1 SunScan canopy analysis system (Delta-T Devices Ltd., Cambridge, UK).

Statistical Analysis of data

From the glasshouse experiment, data of couch grass dry mass were subjected to ANOVA using R (23) to determine the effects of agricultural crops, AC and the crop × AC interaction. Means of each crop effect were compared with the pure stand of couch grass using LSD test using the agricolae package of R (7) ($P < 0.05$). Data on couch grass dry mass from the non-charcoal treatment were regressed on crop RGR. From the field experiment, plant emergence, SSW, LAI, RGRs of 3 growth intervals and weed biomass at three harvest dates were subjected to ANOVA in order to determine the difference caused by different crops. Weed biomass at the final harvest date was individually regressed on SSW, LAI, RGRs of three growth intervals and emergence. These analyses were conducted using Origin 8.6 (OriginLab Co. Northampton, MA, USA).

RESULTS AND DISCUSSION

Weed suppressive factors of crops are: early development, fast and vigorous growth and large leaf area (2,5,11,18,22). This was supported by our results in glasshouse and field experiments, that high RGR and LAI of crops were important to inhibit the weeds growth. In glasshouse experiment, couch grass biomass was the lowest grown with buckwheat in non-charcoal treated boxes followed by faba bean, white lupin, barley and vetch. (Figure 1); and couch grass dry mass was negatively correlated with RGR of crops ($y = -52.1x + 5.62$, $R^2 = 0.49$, Figure 2). Caraway did not affect the couch grass growth due its lower growth rate.

The difference between charcoal treatments was greatest in presence of buckwheat; the activated charcoal doubled the couch grass biomass ($P< 0.05$; Figure 1) indicating that the exudates from buckwheat could additionally inhibit the growth of couch grass. The 4-hydroxyacetophenone, vanillic acid and gallic acid extracted from buckwheat roots inhibited the growth of *Lactuca sativa* L., *Sinapis alba* L., *Achilea milefolium* L.), *Plantago lanceolata* L., *Trifolium repens* L., *Lolium perenne* L., *Echinochloa crus-galli* L. and *Amaranthus retroflexus* L. (12). Buckwheat residues inhibited the growth of green pigweed (*Amaranthus powellii* S. Wats.) *in vitro* (14). It would be interesting to recover its root exudates for bioassay and to investigate the mode of action of allelochemicals.

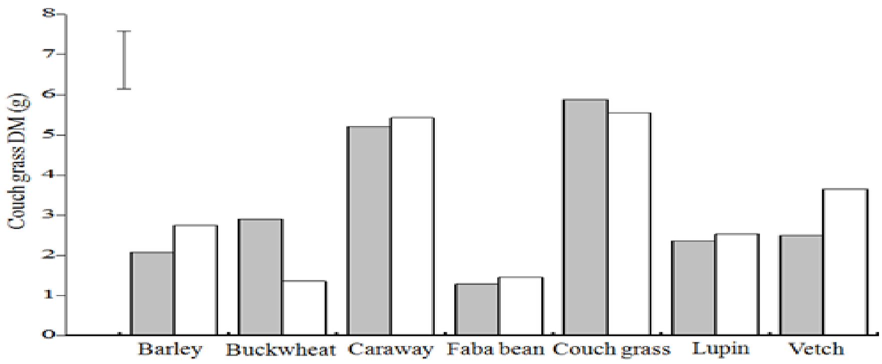

Figure 1. Effects of 7-test crops and incorporation of active charcoal into the soil on above-ground dry mass accumulation of couch grass at42 days after transplanting. With charcoal: Shaded, Without charcoal: White. Mean Data, n =4, LSD, calculated based on d.f. of error = 48, $P < 0.05$ (floating bar).

The success of weed management depends on whether the crop can compete with weed (6) for growth resources (light, nutrients, water, space) and interference by allelochemicals (4,17). In field experiment, each crop created different types of competition for weeds at various growth phases, hence, the weed dry mass (WDM) differed. At 37 DAS, all 4-test crops inhibited the weeds growth than fallow due to competition for growth resources (water, light and nutrients) by crop seedlings (Table 1). However, different seedling emergence of crops did not affect the weed growth significantly.

Table 1.The effects of Emergence, SSW, LAI and relative growth rates of different growth stages of crops on weeds dry mass accumulation

Crop	Emergence	SSW	LAI	RGR/WDM (37 DAS)	RGR/WDM (79 DAS)	RGR/WDM (114 DAS)
Fallow				/108.6	/336.7	/340.2
Buckwheat	127	0.025	3.36	0.129/ 58.2	0.004/ 95.1	0.009/ 88.3
Faba bean	83	0.428	3.22	0.034/ 60.8	0.024/104.8	0.011/114.8
Hemp	139	0.012	2.55	0.123/ 67.7	0.030/196.6	-0.016/264.2
Lupin	67	0.295	3.33	0.072/ 60.2	0.014/138.9	0.018/134.4
LSD ($P < 0.05$)	20.9	0.123	0.33	0.009/ 33.5	0.009/ 54.2	0.015/ 87.5
LSD ($P < 0.01$)	29.4	0.172	0.47	0.013/47.0	0.013/ 76.0	0.021/122.6

Emergence of seedlings of one square meter; SSW, Single seed weight (g); LAI, Leaf area index; RGR, Relative growth rate of three growth intervals (g/g/day); WDM, Weed dry mass collected at 37 DAS, 79 DAS and 114 DAS (g). Data shown are means, n =4, LSD was calculated based on d.f. of error = 12.

At 79 DAS, WDM in hemp was higher than in other crops ($P < 0.01$) because of lowest LAI of hemp. At 114 DAS, WDM was still highest in hemp and the RGR of hemp was negative as the male plants died after flowering. A monoecious cultivar that does not suffer the loss of LAI from the death of male plants may provide better weed suppression.

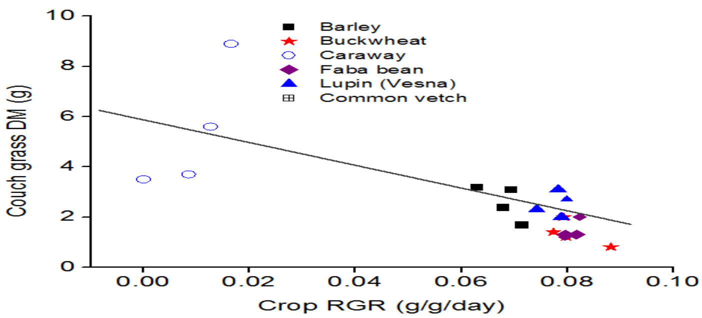

Figure 2. Effects of relative growth rate of 6- test crops on above-ground dry mass of couch grass in boxes without active charcoal.

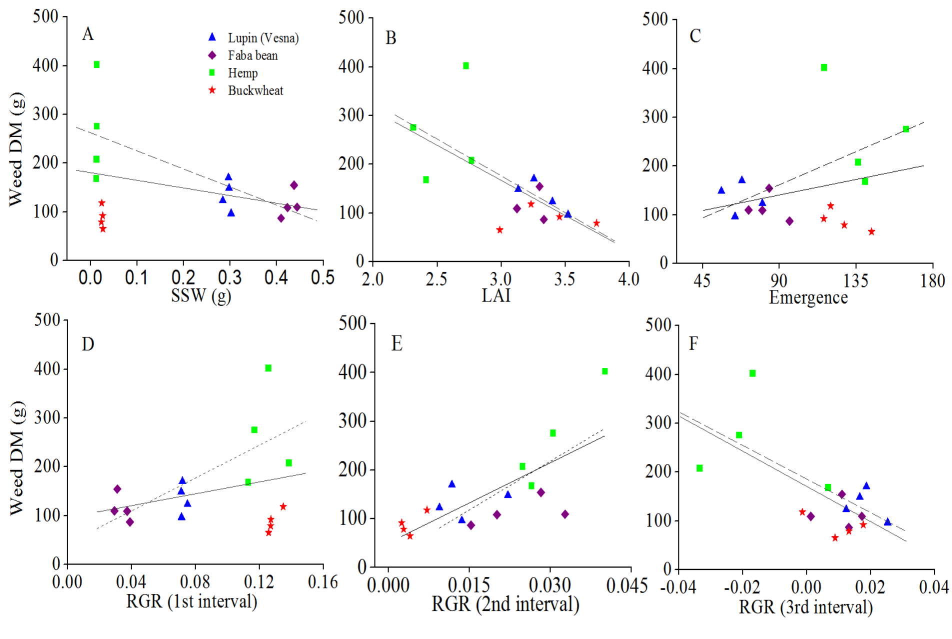

Figure 3. Relationships between crop emergence, single seed weight (SSW), leaf area index (LAI) and relative growth rate (RGR) and weed dry mass at 114 DAS. Solid lines indicate regression based on all data available, and dashed lines indicate regression without buckwheat.

The RGRs of buckwheat in the second and third growth intervals were the lowest, but WDM was lower ($P < 0.01$) than other crops. This indicated that fast growth alone does not inhibit the weed growth, but rapid development of light interception canopy is also required. Quinolizidine alkaloids in white lupin inhibited the weed germination and growth (21,30). However, in this study, no additional inhibitory effect of allelochemicals on weeds was found in glasshouse and field experiments. The decrease of WDM at 114

DAS than at 79 DAS, showed that how the indeterminate growth of white lupin with its increasing LAI continued to compete with weeds. When using plants as source of allelochemicals against weeds, the minimum allelochemicals concentration at which they are toxic to weeds must be reached (3). Therefore, using higher-alkaloid cultivar of white lupin could be more suppressive to weeds.

Buckwheat showed its ability to form weed-inhibitory levels of LAI at early growth stage in glasshouse experiment; its root exudates could additionally inhibit the couch grass growth. The regressions of weed biomass at 114 DAS on various crop growth parameters were strongly affected by buckwheat data (Fig. 3). WDM showed a negative correlation with SSW and a positive one with seedling emergence, but the correlations were stronger when the data of buckwheat was omitted. Moreover, RGR of crops in first growth interval was positively related with WDM, but exclusion of buckwheat data made the correlation much less significant, indicating that buckwheat root exudates affect weed growth at an early stage. In the second growth interval (7 DAS), buckwheat LAI was highest and a small appreciable change in regression excluding buckwheat data showed that combined effects of root exudates and less light interception by weed led to lowest WDM. In the third growth interval (114 DAS) WDM was lower than second growth interval (79 DAS), indicating that senescence of weeds could be accelerated by stresses of physical competition and root exudates.

CONCLUSIONS

The key element to use crop interference for weed management is quick formation of weed-suppressive factors. Caraway, oil seed hemp and common vetch are not promising break crops for weed management due to their slow growth. Weed-suppressive ability of write lupin was lower than faba bean and buckwheat but much higher than caraway, oil seed hemp and common vetch. Use of high- alkaloid-content cultivars of white lupin enhanced the weed-suppressive ability. The weed-suppressive ability of faba bean was slightly lower than buckwheat, the effects of its higher seed rates on weed-suppressive ability and yield needs to be studied. Buckwheat is promising crop for weed management due to its high LAI that effectively shades the weeds and its root exudates inhibitory to weeds. It will be interesting to purify and characterize the weed-suppressive chemicals and investigate the mode of action of root exudates of buckwheat in future.

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