Allelopathic Potential of Winter Cereals and Their Cover Crop Mulch Effect on Grass Weed Suppression and Corn Development

K. V. Dhima,* I. B. Vasilakoglou, I. G. Eleftherohorinos, and A. S. Lithourgidis

ABSTRACT

Field experiments were conducted to study the effect of three rye (*Secale cereale* L.) populations, six triticale (×*Triticosecale* Wittm.) cultivars, and two barley (*Hordeum vulgare* L.) cultivars, used as cover crops, on the emergence and growth of barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.], bristly foxtail [*Setaria verticillata* (L.) P. Beauv.], and corn (*Zea mays* L.). Moreover, bioassay studies were conducted to assess allelopathic potential of the winter cereal extracts on both weed species and corn. All winter cereal extracts reduced barnyardgrass and bristly foxtail seed germination and growth, but none of them had any effect on corn. Bristly foxtail was affected more by all extracts than barnyardgrass, and growth of both weed species was reduced more by the extract of barley cultivar Athinaida. In field, 4 wk after corn planting, barnyardgrass and bristly foxtail emergence was reduced by 27 to 80% and 0 to 67%, respectively, in winter cereal mulched plots compared with that in winter cereal mulch-free plots. On the contrary, corn emergence was not affected by any cover crop mulch. At harvest, corn grain yield increased by 45% in no herbicide treated barley cultivar Athinaida mulched subplots as compared with that in respective mulch-free subplots. This corn yield in no herbicide treated Athinaida mulched subplots was similar with that obtained in respective herbicide-treated subplots. The results of this study suggest that some winter cereals such as barley cultivar Athinaida could be used as cover crop for annual grass weed suppression in corn and consequently to minimize herbicide applications.

Barnyardgrass and bristly foxtail are considered to be among the world's worst weeds (Holm et al., 1977). In addition, barnyardgrass belongs to the 10 most common and troublesome weeds of Greece (Damanakis, 1983) and it is a serious weed problem in corn fields in Ontario (Bosnic and Swanton, 1997).

Cover crops, such as legumes, manage to suppress weeds in corn and increase grain yield (White and Worsham, 1990; Johnson et al., 1993; Yenish et al., 1996). In addition, rye as cover crop caused significant reduction of density and biomass of several weed species in corn and soybean [*Glycine max* (L.) Merr.] (Teasdale et al., 1991; Liebl et al., 1992; Moore et al., 1994). The fact that cover crops suppress weeds could be attributed to their ability to release toxic substances in the environment and to create an unfavorable environment for weed germination and establishment. Teasdale (1996) reported that cover crop residues provided partial weed control during the early stages of crop growth by causing both physical and chemical interference. Several researchers (Ben-Hammouda et al., 2001; Chung et al., 2002; Chon and Kim, 2004) found that rice (*Oryza sativa* L.), barley, wheat (*Triticum aestivum* L.), and oat (*Avena sativa* L.) release toxic substances in the environment either through root exudation or decay of their plant residues. Borner (1960) also indicated that cold water extracts of barley, rye, and wheat straws as well as alcoholic extracts of roots contain phenolic compounds toxic to plant growth. Some of these compounds were ferulic acid (4-hydroxyl-3-methoxy-cinnamic acid), *p*-coumaric acid (4-hydroxy-cinnamic acid), and vanillic acid (hydroxybenzoic acid).

The use of cover crops from a farmer's perspective must be justified economically by reduced herbicide input and/or by increased yield (Reddy, 2001). In cover crop systems, there is an additional cost of seeds, planting, and, in many cases, chemical desiccation compared to a no cover crop system. However, besides improved soil fertility and crop productivity benefits, cover crops can complement chemical weed control and reduce herbicide input through elimination of either preemergence (PRE) or postemergence (POST) herbicide application (Teasdale, 1996; Reddy, 2001; Kuo and Jellum, 2002). Thus, the increased cost associated with a cover crop system can be offset by eliminating either PRE or POST herbicide application compared to a total herbicide (PRE + POST) program.

Previous studies have indicated that rye and legume cover crop mulches have the ability to suppress weeds and affect crop yields, but there is little information on triticale and barley cover crop mulch effects on crop development and weed emergence patterns (Barnes and Putnam, 1983; Moore et al., 1994; Reddy, 2001). Also, the cover crop residues examined, in most cases, did not provide adequate weed control in summer crops, although the cover crop used manage to suppress and/or replace unmanageable winter annual weed species during early spring (Teasdale, 1996).

The objectives of this research were (i) to assess the allelopathic potential of three rye populations, six triticale cultivars, and two barley cultivars and (ii) to determine, under field conditions in northern Greece, the cover crop effect on corn development and on emergence and biomass of two annual grass weeds, barnyardgrass and bristly foxtail.

MATERIALS AND METHODS

Laboratory Experiment

Extract Preparation

Plants of three rye populations originated from Albania, Germany, and Greece, as well as six triticale cultivars (Thisvi,

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Niovi, Vronti, Catria, Vrito, Artemis) and two barley cultivars (Athinaida, Thessaloniki) from Greece were harvested at the beginning of stem elongation and inflorescence emergence. The harvested plants were chopped into 5-cm-long pieces, dried in oven at 70°C for 48 h and grounded in a Wiley mill (Janke & Kunkel, Ika Labartechnik, Staufen, Germany) through a 40-mesh screen. Then, aqueous extracts (w/v) were prepared in 400-mL glass jars by adding 4 or 8 g from each plant sample in 200 mL of deionized water and shook in a horizontal shaker for 4 h at 200 rpm. Three replicate glass jars were used for each plant material by concentration treatment (2 and 4%). The solutions were filtered through four layers of cheesecloth to remove fiber debris, centrifuged at low speed (3100 rpm) for 1 h, and the supernatants were then filtered through a layer of filter paper (Whatman No. 42). The extracts were stored at less than 5°C until bioassayed.

Bioassay Procedure

Petri dish bioassays were performed to compare the germination, total fresh weight, and root length of corn, barnyardgrass, and bristly foxtail in perlite treated with each of the winter cereals extracts. Five corn (F_1 hybrid 'Pioneer Costanza') or 50 of each weed species (barnyardgrass or bristly foxtail) seeds were placed in 8.5-cm-diam. plastic petri dishes and were covered with 6 g of perlite. The open petri dishes were moistened with 15 mL of winter cereal extract per petri dish from each of the winter cereal extracts. Deionized water was used in control petri dishes. Afterward, the petri dishes were stored on shallow trays and were placed inside in a plastic bag to retain moisture. The trays were then placed in an illuminated (16:8 h light/dark) growth chamber at 27 ± 2°C for 8 d. At the end of the incubation period, plants were removed from the petri dishes and carefully washed free of perlite, and average germination, total fresh weight, and root length were measured. Percentage inhibition was calculated by the Eq. [1] used by Chung et al. (2001):

$$\text{Inhibition percentage (\%)} = 100[(\text{control} - \text{extracts})/\text{control}] \quad [1]$$

Two petri dishes were used for each jar and petri dishes were arranged in a completely randomized design. The experiment was repeated twice. Fungal contamination was not observed during these experiments.

Field Experiment

Winter Cereal Cultivation

Two field experiments were conducted during 2001–2002 and 2002–2003 growing seasons at the University Farm of Thessaloniki in northern Greece. The site was located at 22°59′6.17″ N, 40°32′9.32″ E. Experiments were established on a calcareous loam soil (Typic Xerorthent) whose physicochemical characteristics were silt 48%, clay 27%, sand 25%, organic matter 1.5%, and pH (1:2 H_2O) 8.3.

Nitrogen and P were applied at 50 kg ha^{-1} and 66 kg ha^{-1} and incorporated into the soil before winter cereal planting. The 11 winter cereals mentioned above were planted at a seed rate of 160 kg ha^{-1} on 7 Dec. 2001 and 25 Nov. 2002. A randomized complete block design with four replications for each treatment was used. Plot size was 9 by 4 m and a 2-m-wide alley separated all plots. In both growing seasons, herbicides were not used on crops because of their low weed infestation. However, in plots where winter cereals had not been planted, weed control was achieved with 0.6 kg ha^{-1} of paraquat (1,1′-dimethyl-4,4′-bipyridinium) applied postemergence 3 wk before winter cereal incorporation into the soil. Other cultural practices were performed according to the recommended production practices for the area.

Corn Cultivation

In spring of 2002 and 2003, the winter cereals were incorporated into the soil (8–10 cm depth) and 15 d later the experimental area was infested by broadcasting of 12 g m^{-2} and 6 g m^{-2} of barnyardgrass and bristly foxtail seeds, respectively. Then, the weed seeds were incorporated into the soil (5 cm depth) with a rotovator and corn planted. The barnyardgrass and bristly foxtail seeds were harvested from a nearby area during the previous year for each experiment.

Before corn planting, 170 kg N ha^{-1} and 70 kg P ha^{-1} were incorporated into the soil. Also, 100 kg ha^{-1} of N was applied 35 d after corn planting. Corn F_1 hybrid (Pioneer Costanza) was planted in a 80-cm rows at an approximate density of 62 500 seed ha^{-1}. The planting dates were 24 Apr. 2002 and 29 Apr. 2003. A split plot approach was employed in a randomized complete block design with four replicates. Plot size was 9 by 4 m. In each plot, two subplots of 4 by 4 m were created (included four rows of corn), and all subplots were separated by a 1-m-wide alley. The 11 winter cereals plus the winter cereal–free (control) plots was the main plot factor, while the crop by chemical weed control (with or without herbicide application at 4 wk after corn planting) was the subplot factor. Barnyardgrass and bristly foxtail control in these subplots was achieved with 0.04 kg a.i. ha^{-1} of nicosulfuron (2-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]-*N,N*-dimethyl-3-pyridinecar-boxamide) applied postemergence on corn or by hand-weeding. Also, broadleaf weeds in herbicides untreated subplots were hand-removed during both growing seasons.

Insect management was conducted with 1.2 kg a.i. ha^{-1} of carbofuran (2,3-dihydro-2,2-dimethylbenzofuran-7-ylmethylcarbamate) applied at the time of corn planting. Irrigation and other common cultural practices were conducted as needed during the growing season. Mean monthly temperature and rainfall data recorded near the experimental area are given in Fig. 1.

Crop and weed densities were determined 4 wk after planting (WAP). Also, barnyardgrass and bristly foxtail plants were harvested in a 1-m^2 area in the two center rows of each subplot 12 and 16 WAP in both growing seasons. Weed stem number and fresh weight were determined at each sampling.

At the silage stage (when the kernels began to glaze) of corn (14 WAP), 20 plants (4 m of row) were harvested from each subplot and the silage yield was recorded. The silage stage was determined by breaking the ears of corn and visually evaluating the kernels' stage of development. At grain maturity (middle September for both growing seasons), ears of corn plants (of the two 4-m-long center rows of each subplot) were hand-harvested, and grain yield (adjusted to 15.5% moisture content) was determined.

Statistical Analysis

A combined over time analysis of variance (ANOVA) was performed for germination, total fresh weight, and root length inhibitory percentage data of the laboratory experiment by using a factorial approach (winter cereal species × extract concentration). Differences between means were compared at the 5% level of significance using the Fisher's Protected LSD test. Because the analysis of variance indicated no significant treatment × repetition time interaction, the means of each extract concentration averaged over the two experiments are presented.

Data for barnyardgrass and bristly foxtail stem number and

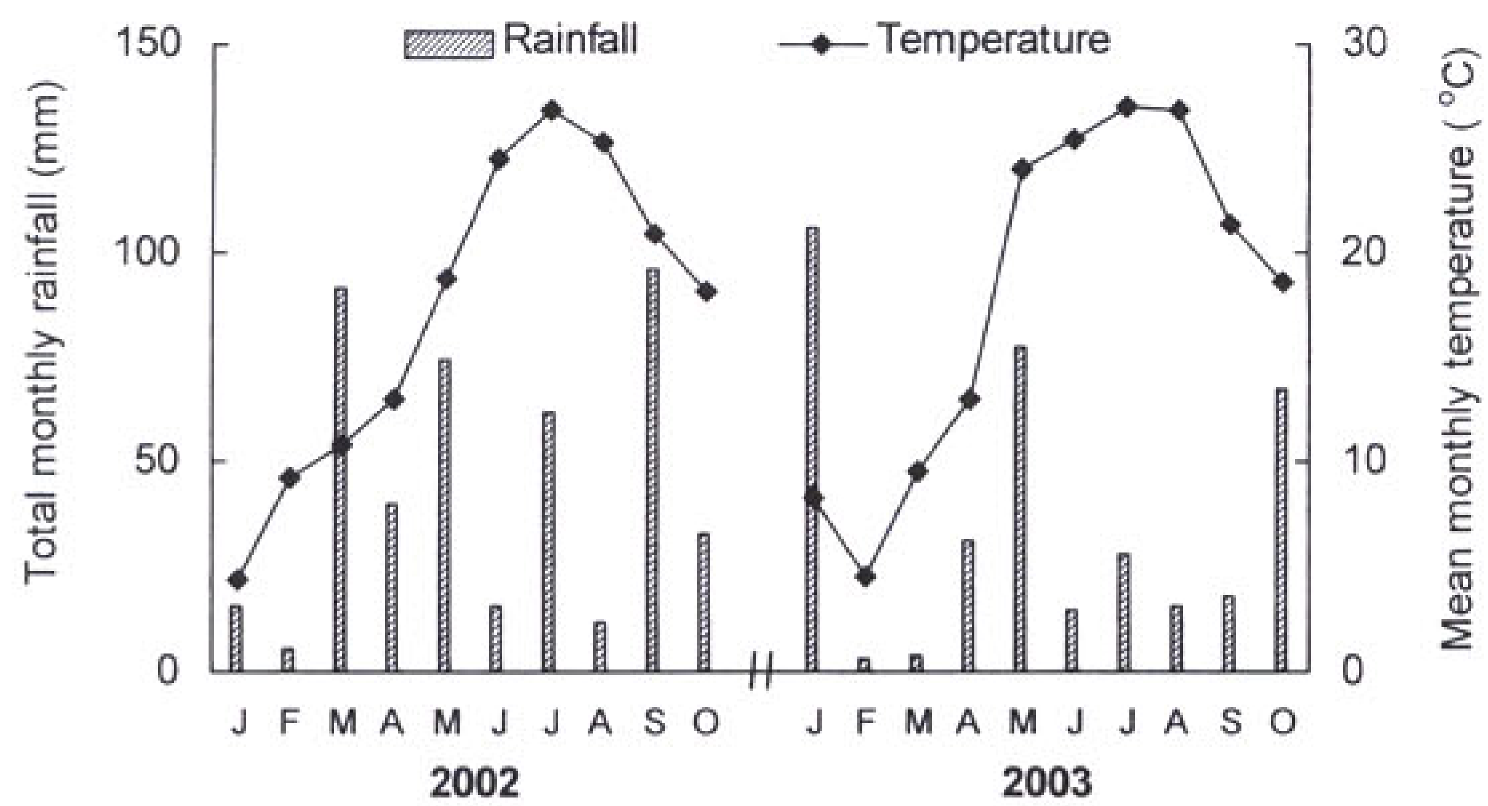

Fig. 1. Total monthly rainfall and mean monthly temperature during the experiment.

fresh weight as well as corn silage and grain yield data were analyzed over year and means were compared at the 5% level of significance using the Fisher's Protected LSD test. Also, because the analysis of variance indicated significant treatment × time interaction, the means of each year are presented. MSTAT program was used to conduct the analysis of variance.

RESULTS AND DISCUSSION

Laboratory Experiment

Corn germination, root length, and seedling fresh weight were not affected by winter cereals extracts (data not shown), while those of barnyardgrass and bristly foxtail were significantly affected by both winter cereal species ($P < 0.001$) and extract concentration ($P < 0.001$). In particular, barley cultivar Athinaida extract of 4 g 100 mL^{-1} deionized water inhibited germination of barnyardgrass and bristly foxtail by 39 and 64%, respectively, while the respective inhibition by extract concentration of 2 g 100 mL^{-1} deionized water was 11 and 35% (Fig. 2 and 3). Also, barley cultivar Thessaloniki and triticale cultivar Vronti extracts of 4 g 100 mL^{-1} deionized water inhibited germination of bristly foxtail by 45 and 50%, respectively. On the contrary, the corresponding inhibition of barnyardgrass germination was 6 and 10%. In relation to the other winter cereals extracts, the germination inhibition percentage of barnyardgrass, as averaged across the two extract concentrations, ranged from 0 to 14%, while the corresponding inhibition of bristly foxtail germination ranged from 17 to 29% (Fig. 2 and 3).

In most cases, winter cereal extracts caused greater seedling fresh weight inhibition of bristly foxtail than that of barnyardgrass (Fig. 2 and 3). In particular, the barley cultivar Athinaida and triticale cultivar Catria extracts of 4 g 100 mL^{-1} deionized water reduced barnyardgrass seedling total fresh weight by 69 and 54%, respectively. The corresponding seedling total fresh weight inhibition of bristly foxtail was 81 and 67%. In addition, barley cultivar Thessaloniki and rye population from Germany and Greece extracts of 4 g 100 mL^{-1} deionized water caused similar reduction (51–52%) on seedling fresh weight of barnyardgrass (Fig. 2). However, seedling total fresh weight inhibition of barnyardgrass by the concentration of 2 g 100 mL^{-1} deionized water ranged

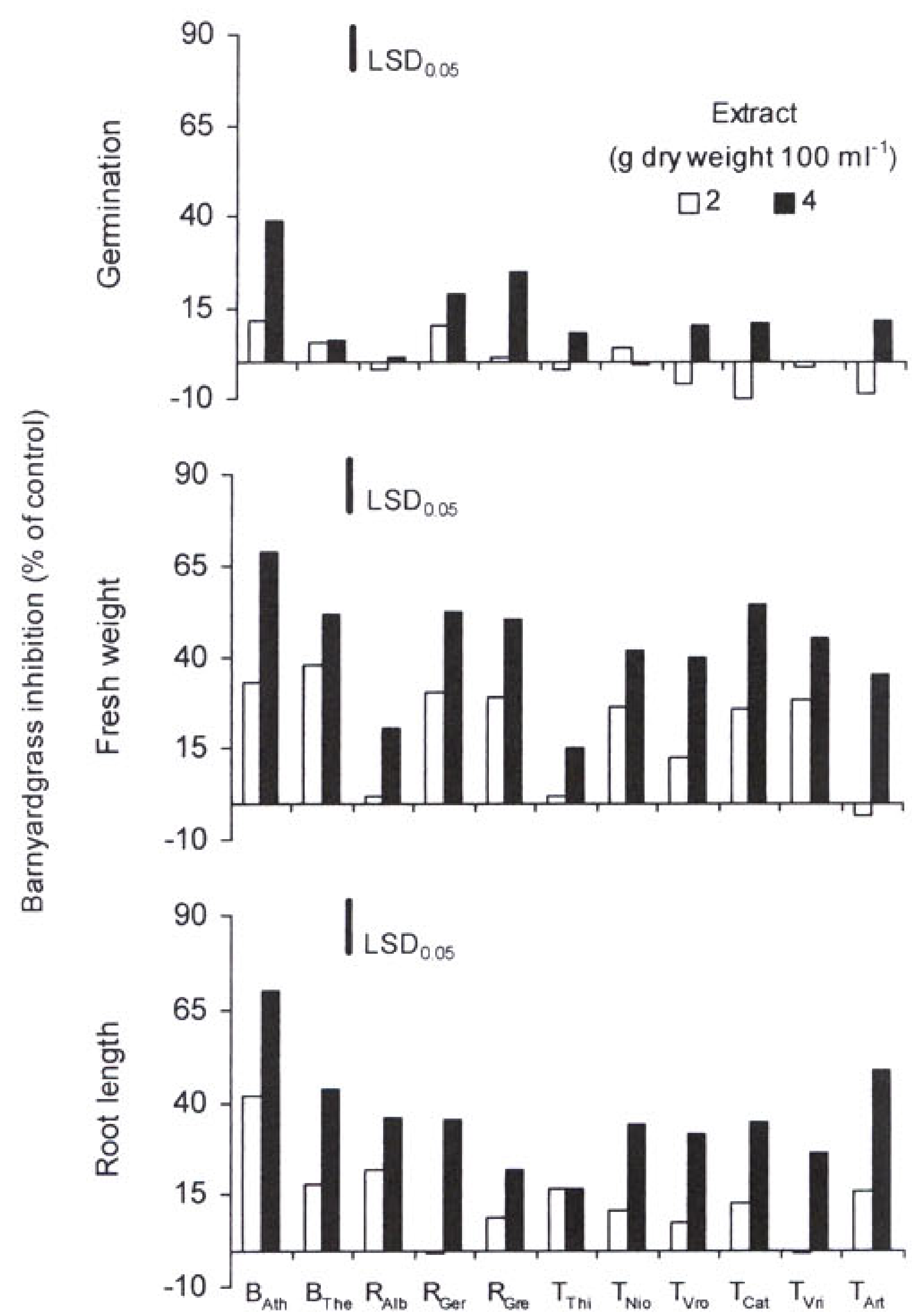

Fig. 2. Inhibitory effect (percentage of water control) of 11 winter cereal extracts on barnyardgrass seedling germination, total fresh weight, and root length. Means are averaged over two experiments. B_{Ath}, barley Athinaida; B_{The}, barley Thessaloniki; R_{Alb}, rye Albania; R_{Ger}, rye Germany; R_{Gre}, rye Greece; T_{Thi}, triticale Thisvi; T_{Nio}, triticale Niovi; T_{Vro}, triticale Vronti; T_{Cat}, triticale Catria; T_{Vri}, triticale Vrito; T_{Art}, triticale Artemis.

from 0 to 37%, while the corresponding reduction of bristly foxtail ranged from 6 to 24% (Fig. 2 and 3).

Winter cereal extracts at the concentration of 2 g 100 mL^{-1} deionized water reduced root length of bristly foxtail more than that of barnyardgrass (Fig. 2 and 3). Also, barley cultivar Athinaida and triticale cultivar Ar-

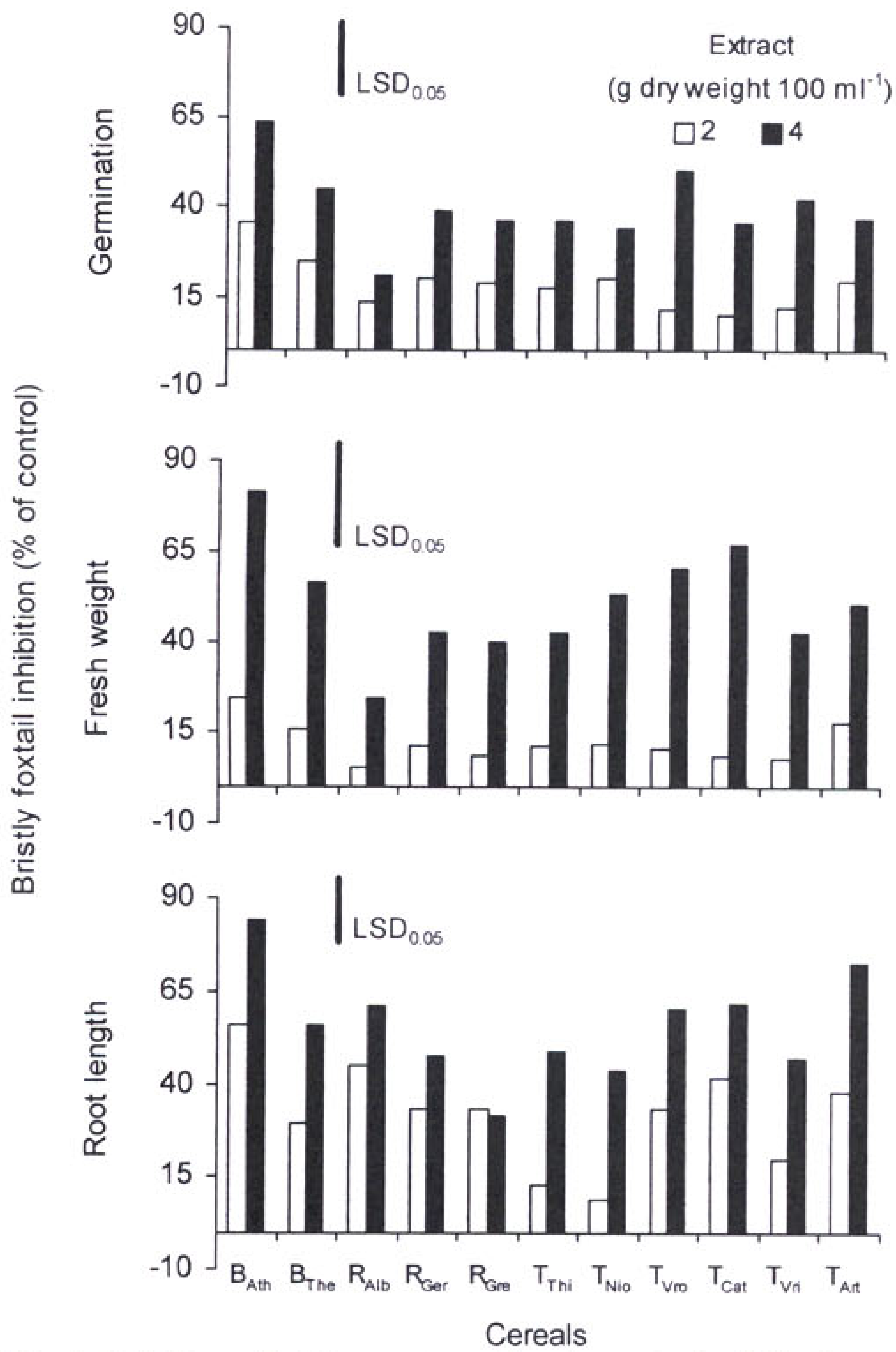

Fig. 3. Inhibitory effect (percentage of water control) of 11 winter cereal extracts on bristly foxtail seedling germination, total fresh weight, and root length. Means are averaged over two experiments. B_{Ath}, barley Athinaida; B_{The}, barley Thessaloniki; R_{Alb}, rye Albania; R_{Ger}, rye Germany; R_{Gre}, rye Greece; T_{Thi}, triticale Thisvi; T_{Nio}, triticale Niovi; T_{Vro}, triticale Vronti; T_{Cat}, triticale Catria; T_{Vri}, triticale Vrito; T_{Art}, triticale Artemis.

temis extracts of 4 g 100 mL^{-1} deionized water caused the greater root length inhibition of barnyardgrass and bristly foxtail. In particular, root length inhibition of barnyardgrass was 70 and 48%, respectively, while the corresponding reduction of bristly foxtail was 84 and 73%. However, root length inhibition of barnyardgrass caused by barley cultivar Athinaida and triticale cultivar Artemis extracts of 2 g 100 mL^{-1} deionized water was 42 and 16%, respectively, while the respective reduction of bristly foxtail was 56 and 38% (Fig. 2 and 3).

The greater germination, root length, and seedling fresh weigh inhibition of bristly foxtail compared with that of barnyardgrass is in agreement with results reported by Burgos and Talbert (2000) who found that small-seeded vegetable crops were affected by rye extracts more than large-seeded crops. The lack of significant corn germination and root length inhibition by the cereal extracts agree with the findings of Ben-Hammouda et al. (2001) who reported that extracts of barley plants did not significantly affect seed germination of either durum (*Triticum durum* L.) or bread wheat (*Triticum aestivum* L.) cultivars. In addition, Chon and Kim (2004) found that extracts from barley, oats, rice, and wheat inhibited root length of barnyardgrass and alfalfa (*Medicago sativa* L.) differently. However, Barnes and Putnam (1987) found that barnyardgrass was less sensitive to rye hydroxamic acids DIBOA (2,4-dihydroxy-1,4-benzoxazin-3-one) and BOA (benzoxazolin-2-one) compared to large crabgrass [*Digitaria sanguinalis* (L.) Scop.] and proso millet (*Panicum miliaceum* L.).

The inhibition of barnyardgrass and bristly foxtail seed germination, seedling total fresh weight and root length by the extracts of the 11 winter cereals could be attributed to their allelopathic potential characteristics. Also, the recorded differences in response of the two annual grass weeds could be related to the chemical differences among the crop extracts, since the extracts were of the same concentrations. Similar results were reported by Chung et al. (2001), Hanson et al. (1981), and Burgos et al. (1999) who worked with rice, barley, and rye cultivars, respectively. Also, the allelopathic substances found in cereals were reported to belong to the amine alkaloid class known as gramines (Hanson et al., 1981; Ahmad et al., 1985) as well as in hydroxamic acids (Burgos and Talbert, 2000).

The greater root length inhibition of barnyardgrass and bristly foxtail by the winter cereal extracts in comparison with that of germination is in agreement with the findings of Hedge and Miller (1992), Chung and Miller (1995), and Chon et al. (2000).

The increased barnyardgrass and bristly foxtail emergence, fresh weight, and root length inhibition with increasing extract concentration agree with results reported by Burgos and Talbert (2000) and Chon and Kim (2004). In addition, Chung et al. (2002) found that the inhibition of barnyardgrass seedling total dry weight increased with increasing concentrations of ferulic acid, m-coumaric acid, *p*-hydroxybenzoic acid, and mixed chemicals originated from rice hulls. Einhellig and Souza (1992) and Nimbal et al. (1996) also found that root and shoot growth of barnyardgrass, crabgrass, velvetleaf (*Abutilon theophrasti* Medik.), jimsonweed (*Datura stramonium* L.), and redroot pigweed (*Amaranthus retroflexus* L.) were reduced with the increase of sorgoleone concentration.

The greater phytotoxic effect on barnyardgrass and bristly foxtail caused by the extracts of barley cultivar Athinaida than by any other winter cereal is in agreement with results reported by Chon and Kim (2004) who found that barnyardgrass root growth was inhibited by barley extracts more than by oat ones. This fact could be related to differences on total amount and physicochemical characteristics of allelochemicals produced by these winter cereals (Burgos et al., 1999; Burgos and Talbert, 2000).

Field Experiment

The analysis of variances (ANOVA) of the weed data indicated that, in most cases, barnyardgrass and bristly foxtail stem number and fresh weight were significantly affected by growing season ($P < 0.001$), winter cereal cover crop ($P < 0.001$), and their interactions ($P <$

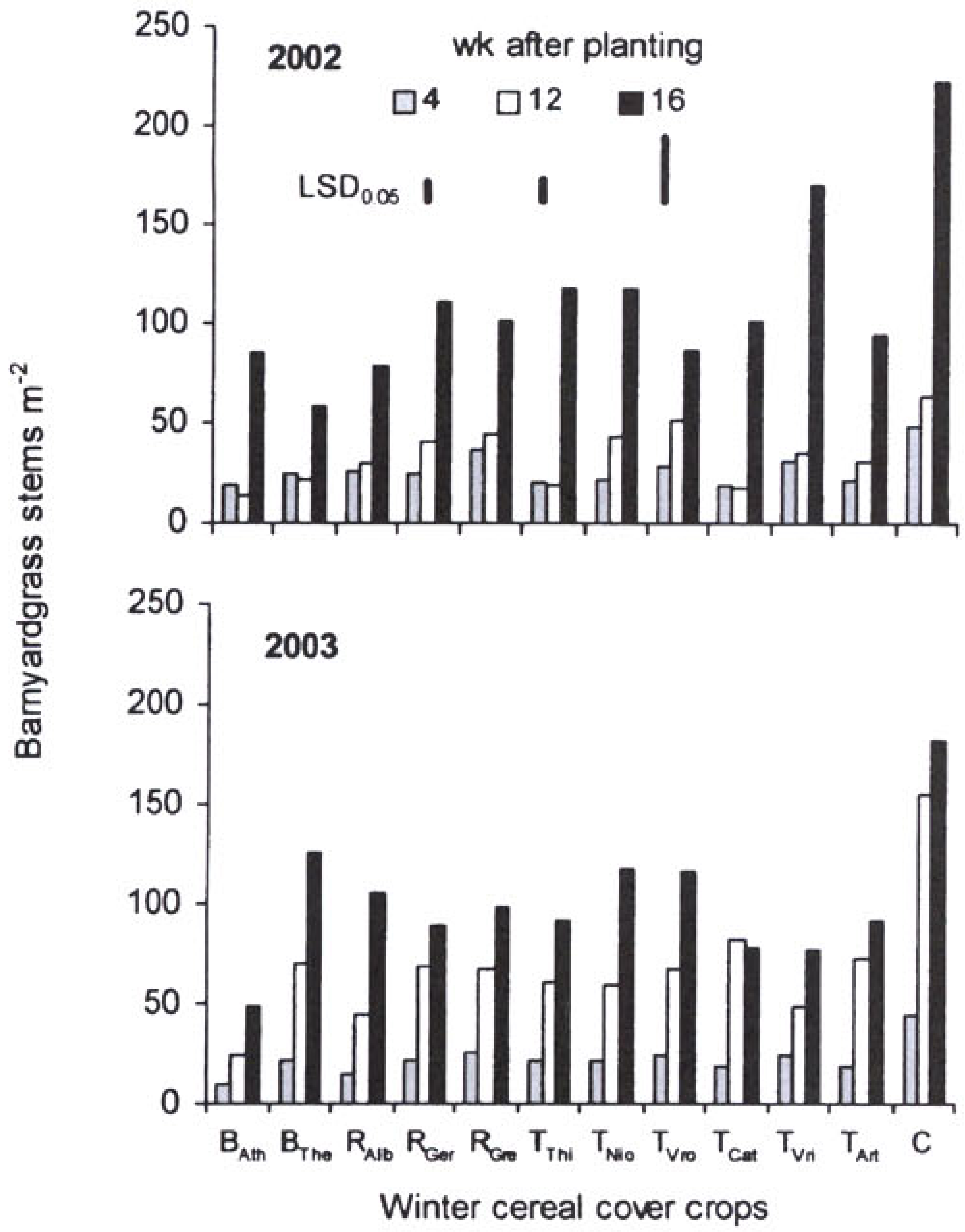

Fig. 4. Effect of 11 winter cereal cover crop mulches on barnyardgrass shoot number grown in corn. B_{Ath}, barley Athinaida; B_{The}, barley Thessaloniki; R_{Alb}, rye Albania; R_{Ger}, rye Germany; R_{Gre}, rye Greece; T_{Thi}, triticale Thisvi; T_{Nio}, triticale Niovi; T_{Vro}, triticale Vronti; T_{Cat}, triticale Catria; T_{Vri}, triticale Vrito; T_{Art}, triticale Artemis; C, control.

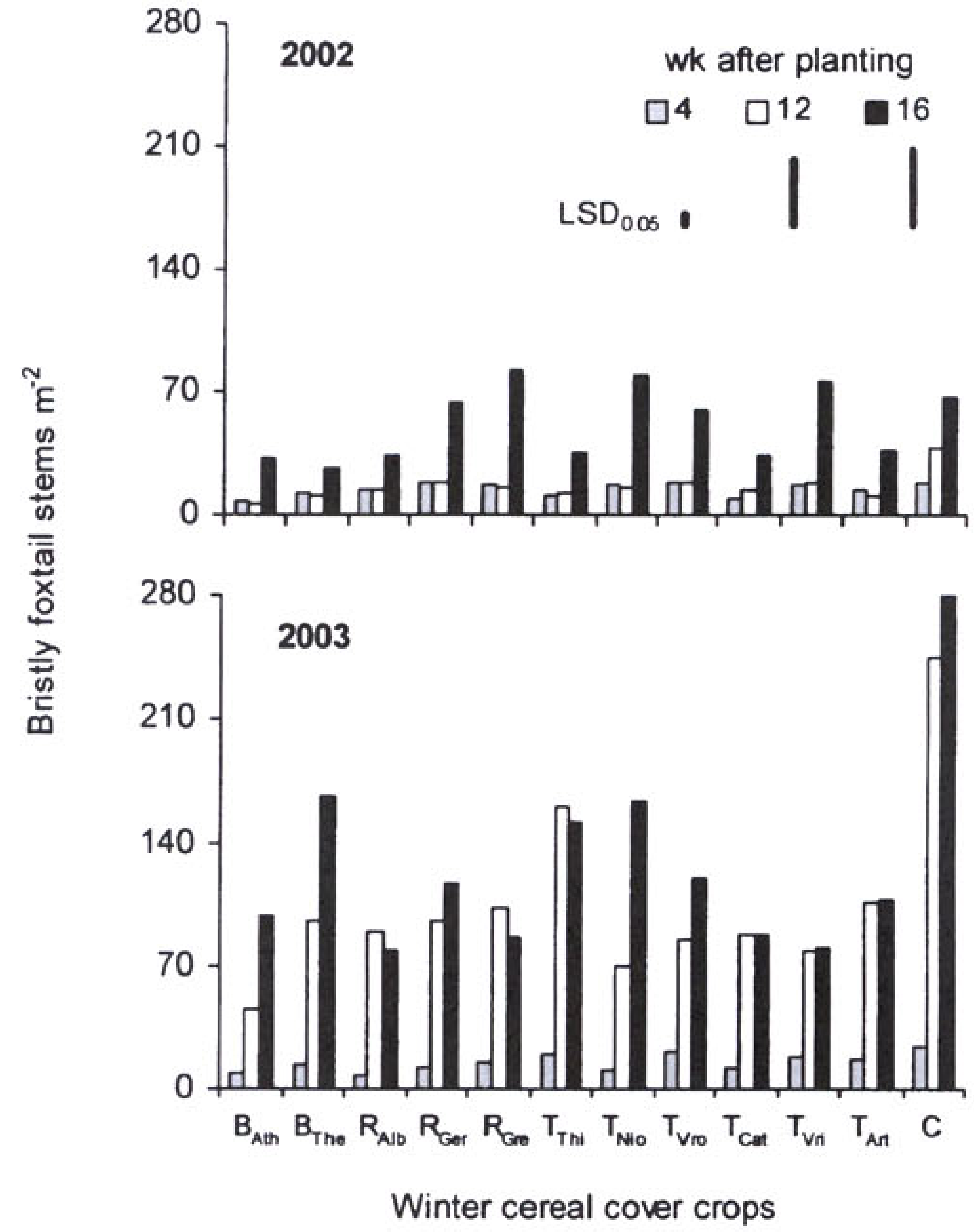

Fig. 5. Effect of 11 winter cereal cover crop mulches on bristly foxtail shoot number grown in corn. B_{Ath}, barley Athinaida; B_{The}, barley Thessaloniki; R_{Alb}, rye Albania; R_{Ger}, rye Germany; R_{Gre}, rye Greece; T_{Thi}, triticale Thisvi; T_{Nio}, triticale Niovi; T_{Vro}, triticale Vronti; T_{Cat}, triticale Catria; T_{Vri}, triticale Vrito; T_{Art}, triticale Artemis; C, control.

0.001). So, the growing season × winter cereal cover crop means are presented (Fig. 4, 5, 6, and 7).

Stem number of barnyardgrass and bristly foxtail by 4 wk of growth was less in plots where winter cereals were incorporated compared with those of winter cereal cover crop mulch-free plots (Fig. 5 and 6). In particular, in plots where barley cultivar Athinaida was incorporated in 2001, barnyardgrass and bristly foxtail stem number was reduced by 61 and 56%, respectively, compared with winter cereal cover crop mulch-free plots (control). The corresponding stem number reduction in 2002 was 80 and 62%, respectively. However, in plots where the other winter cereals were incorporated, barnyardgrass and bristly foxtail stem number reduction, averaged across growing seasons, ranged from 34 to 60% and 7 to 50%, respectively (Fig. 4 and 5). At 12 WAP, barley cultivar Athinaida cover crop mulches caused again the greatest barnyardgrass and bristly foxtail stem number reduction compared with those caused by the other winter cereals studied. In particular, barnyardgrass and bristly foxtail stem number reduction caused by Athinaida cover crop mulches was 83% for both weeds, averaged across growing seasons (Fig. 4 and 5). At 16 WAP of 2002 growing season, cover crop mulches of rye population from Greece as well as triticale cultivars Niovi and Vrito caused the least barnyardgrass and bristly foxtail stem number reduction, which ranged from 0 to 55% as averaged across weed species (Fig. 4 and 5). However, in 2003 growing season, the least barnyardgrass and bristly foxtail stem number reduction caused by barley Thessaloniki and triticosecale Niovi cultivars and ranged from 31 to 36% and 40 to 41%, respectively. On the contrary, at the same sampling (16 WAP) of both growing seasons, barley cultivar Athinaida cover crop mulches caused again the greatest barnyardgrass and bristly foxtail stem number reduction, which ranged from 62 to 73% and 52 to 65%, respectively (Fig. 4 and 5).

Total fresh weight of barnyardgrass and bristly foxtail reduction by cereal mulches, averaged across growing seasons and samplings, ranged from 47 to 81% and form 27 to 72%, respectively (Fig. 6 and 7). In particular, the greatest barnyardgrass and bristly foxtail total fresh weight reduction caused again by barley cultivar Athinaida (79 and 67%, respectively). On the contrary, the lower barnyardgrass total fresh weight reduction caused by the rye populations from Germany and Greece (52%) and the less bristly foxtail total fresh weight reduction caused by triticale cultivar Vrito (32%).

Corn emergence was not significantly affected by the presence of winter cereal cover crop mulches (data not shown). However, corn silage yield was significantly affected by growing season ($P < 0.01$), herbicide application ($P < 0.001$), and by the growing season × herbi-

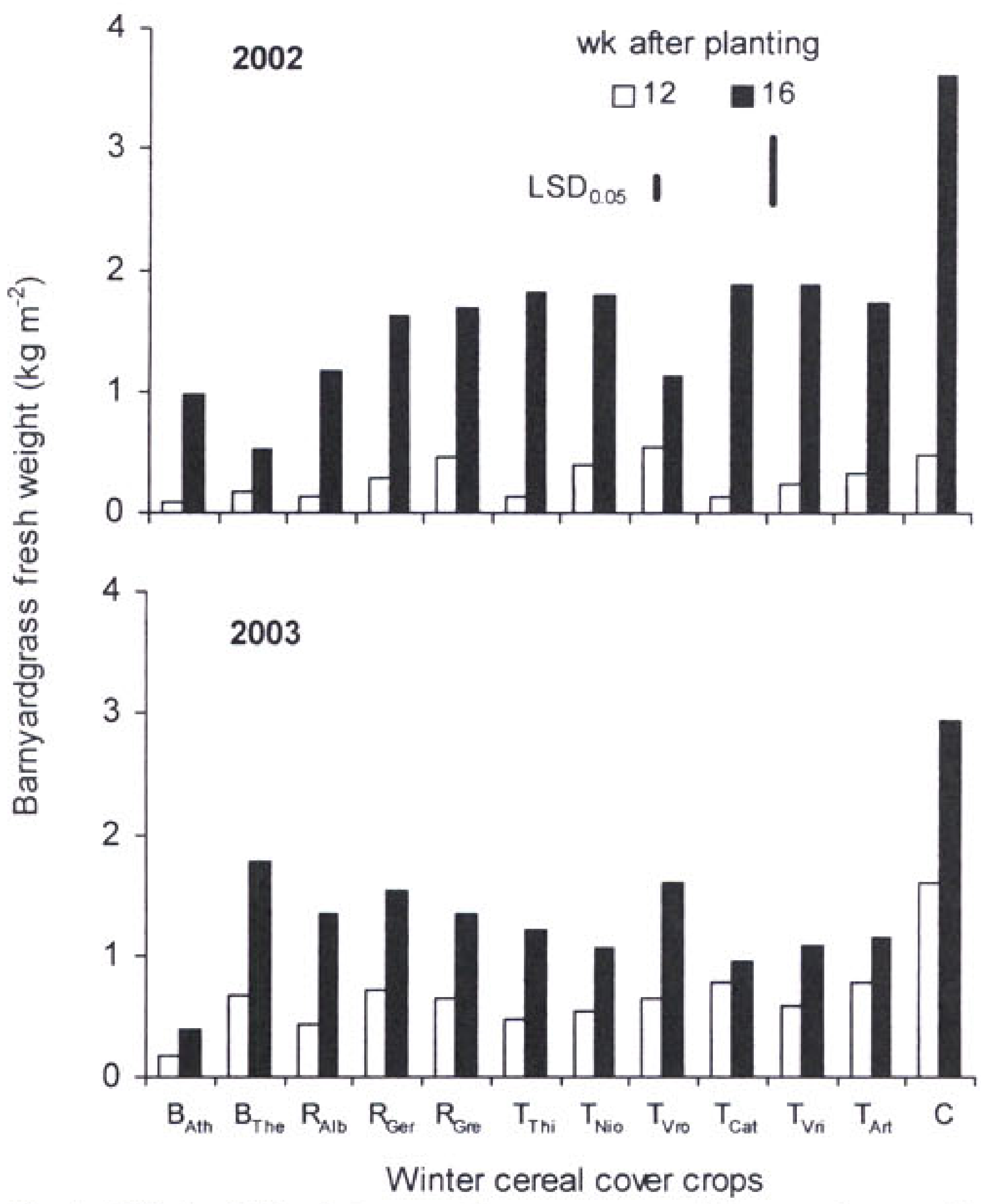

Fig. 6. Effect of 11 winter cereal cover crop mulches on barnyardgrass fresh weight grown in corn. B_{Ath}, barley Athinaida; B_{The}, barley Thessaloniki; R_{Alb}, rye Albania; R_{Ger}, rye Germany; R_{Gre}, rye Greece; T_{Thi}, triticale Thisvi; T_{Nio}, triticale Niovi; T_{Vro}, triticale Vronti; T_{Cat}, triticale Catria; T_{Vri}, triticale Vrito; T_{Art}, triticale Artemis; C, control.

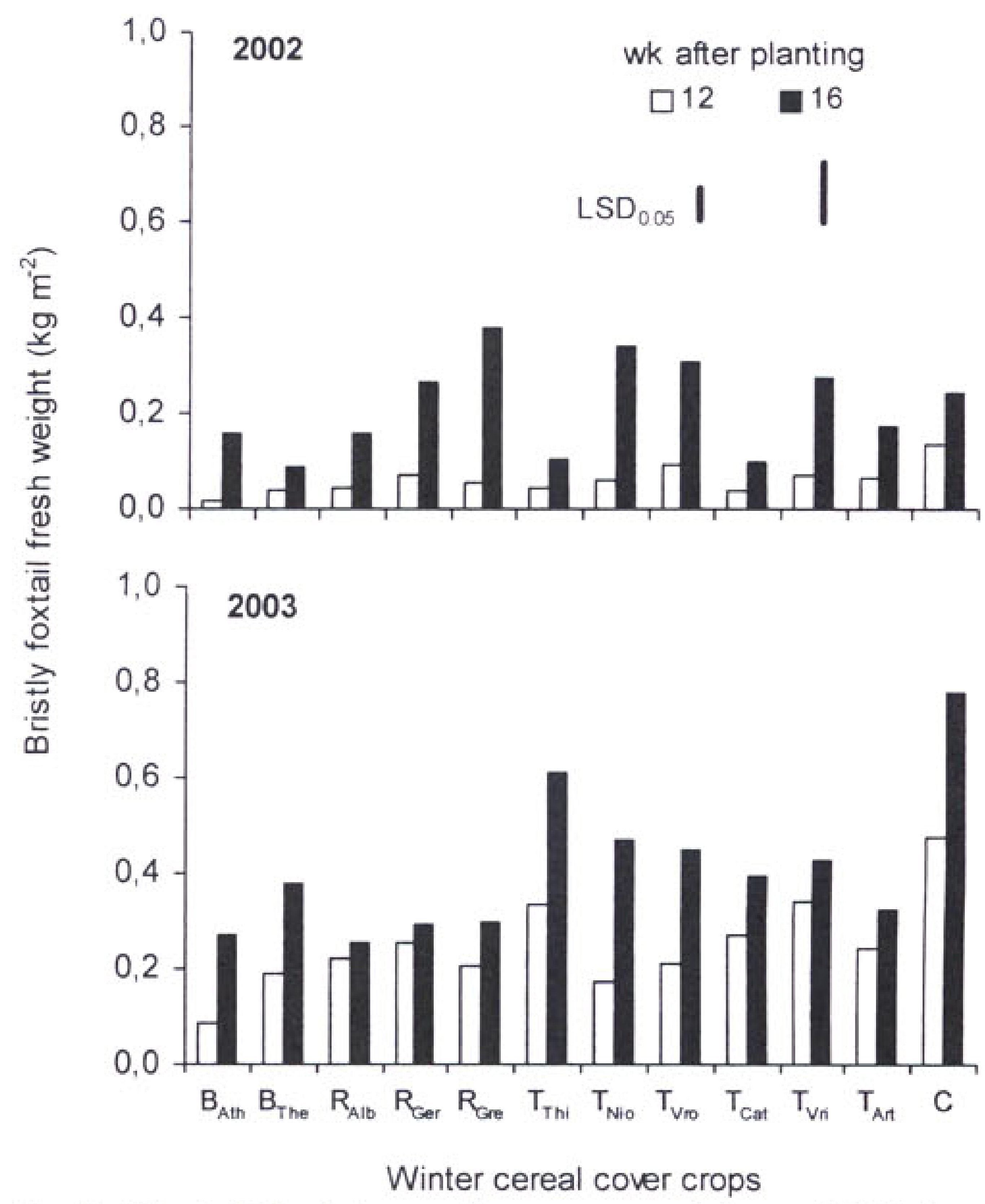

Fig. 7. Effect of 11 winter cereal cover crop mulches on bristly foxtail fresh weight grown in corn. B_{Ath}, barley Athinaida; B_{The}, barley Thessaloniki; R_{Alb}, rye Albania; R_{Ger}, rye Germany; R_{Gre}, rye Greece; T_{Thi}, triticale Thisvi; T_{Nio}, triticale Niovi; T_{Vro}, triticale Vronti; T_{Cat}, triticale Catria; T_{Vri}, triticale Vrito; T_{Art}, triticale Artemis; C, control.

cide application interaction ($P < 0.05$). Also, corn grain yield was significantly affected by herbicide application ($P < 0.001$) and the interactions of growing season × herbicide application ($P < 0.01$), winter cereal cover crop × herbicide application ($P < 0.001$), and growing season × winter cereal cover crop × herbicide application ($P < 0.05$). So, the growing season × winter cereal cover crop × herbicide application interaction means are presented (Fig. 8 and 9).

In both growing seasons, the corn silage yield in subplots where winter cereals had been incorporated and the two grass weeds controlled by nicosulfuron application was similar to that of the corresponding subplots where cereals had not been planted (Fig. 8). Also, averaged across growing seasons, in herbicide untreated subplots where barley cultivar Athinaida, rye population from Germany, and triticale cultivars Catria and Artemis had been incorporated, corn silage yield increased by 15 to 20%, as compared with the respective subplots where cereals had not been planted (control). In addition, averaged across growing seasons, corn silage yield, in herbicide treated subplots where barley cultivar Athinaida and triticale cultivar Niovi had incorporated, was similar to that of respective herbicide untreated subplots. On the contrary, in herbicide untreated subplots where triticale cultivars Thisvi, Vrito, and Vronti had incorporated, corn silage yield was decreased by 14, 19, and 33%, respectively, compared with the corresponding herbicide treated subplots (Fig. 8).

At harvest, averaged across growing seasons, corn grain yield in herbicide untreated subplots (except subplots where barley cultivar Athinaida had incorporated), was decreased by 10 to 31%, as compared with the corresponding herbicide treated subplots (Fig. 9). On the contrary, corn grain yield, in herbicide untreated subplots where barley cultivar Athinaida had incorporated, was similar to that of the corresponding herbicide treated subplots. In addition, this grain yield was 45% higher than that of untreated subplots where cereals had not been planted (control) (Fig. 9).

The corn yield reduction due to the presence of the two grass weeds in herbicide untreated subplots is in agreement with results reported by Bosnic and Swanton (1997). Also, the lack of corn yield reduction in herbicide treated subplots agree with the findings of Yenish et al. (1996) who reported that corn grain yield in subplots where PRE or PRE plus POST-applied herbicides were used was 16 to 100% greater than that of the untreated subplots (control), averaged across all cover crop treatments.

The significant inhibition of barnyardgrass and bristly foxtail emergence and growth by the winter cereal cover crop mulches agree with results reported by Reddy (2001) who found that rye, oat, wheat, and hairy vetch (*Vicia villosa* Roth) cover crop residues suppressed browntop millet [*Brachiaria ramosa* (L.) Stapf] in soybean. Teasdale et al. (1991) also found that carpetweed (*Mollugo verticillata* L.) and common lambsquarters

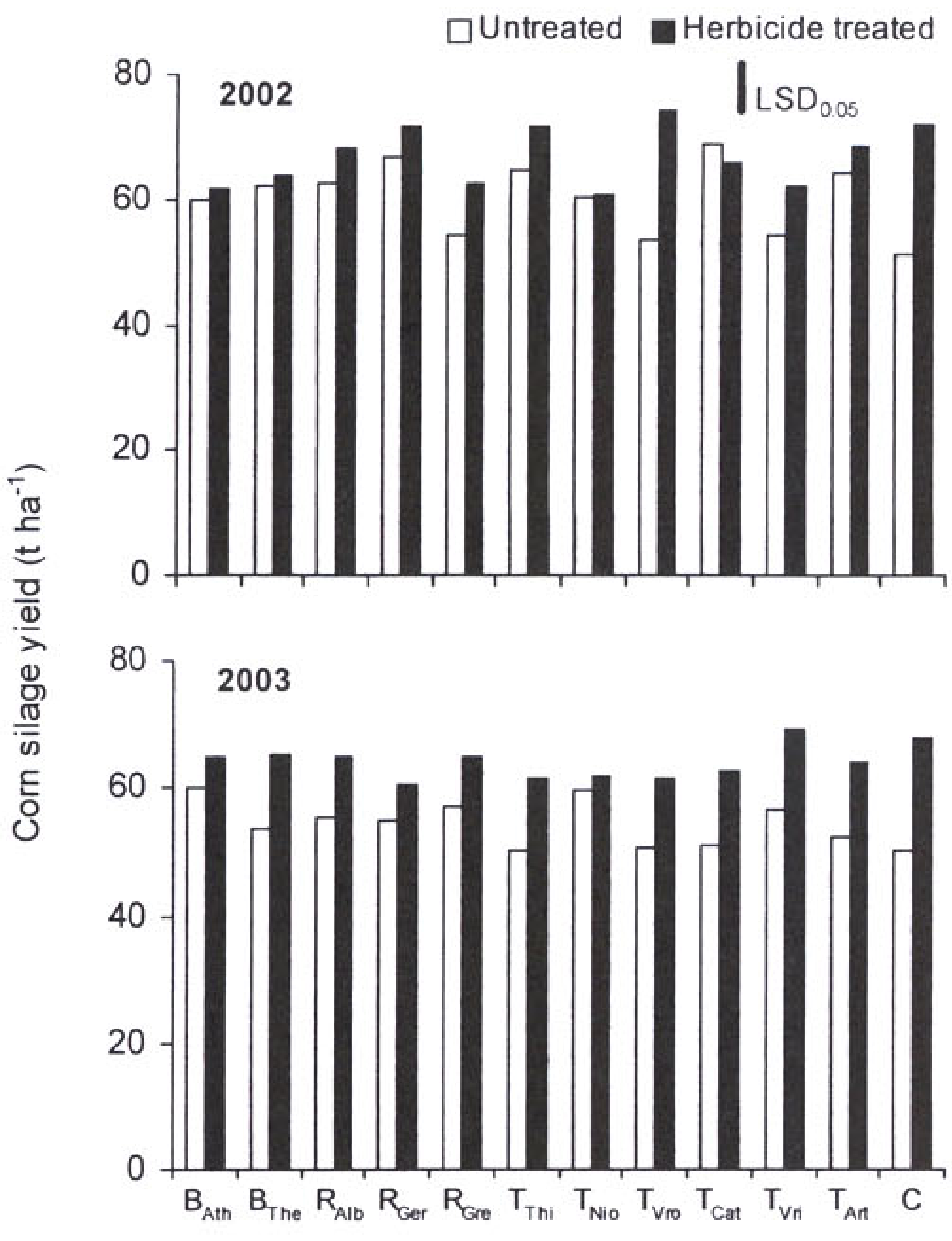

Fig. 8. Effect of 11 winter cereal cover crop mulches and two grasses (barnyardgrass and bristly foxtail) on corn silage yield. B_{Ath}, barley Athinaida; B_{The}, barley Thessaloniki; R_{Alb}, rye Albania; R_{Ger}, rye Germany; R_{Gre}, rye Greece; T_{Thi}, triticale Thisvi; T_{Nio}, triticale Niovi; T_{Vro}, triticale Vronti; T_{Cat}, triticale Catria; T_{Vri}, triticale Vrito; T_{Art}, triticale Artemis; C, control.

(*Chenopodium album* L.) density was suppressed by rye and hairy vetch cover crop residues. Finally, Barnes and Putnam (1983) and Weston (1990) reported that cover crops such as rye, barley, and wheat reduced early season biomass of various weeds by 48 to 98%, compared to no cover crop controls. On the contrary, Reddy (2001) found that barnyardgrass density was not affected by rye, oat, wheat, and hairy vetch used as cover crops. In addition, Teasdale et al. (1991) found that large crabgrass density was not affected by rye and hairy vetch cover crop residues and Moore et al. (1994) found that redroot pigweed and common lambsquarters emergence were not affected by rye and wheat residues compared to no cover crop.

The increased corn yield by the postemergence herbicide application agree with the results found by Johnson et al. (1993) and Yenish et al. (1996) who studied the effect of rye, hairy vetch, crimson clover (*Trifolium incarnatum* L.), and subterranean clover (*Trifolium subterraneum* L.) cover crops on corn.

The lack of corn silage and grain yield reduction by the presence of cover crop mulches, in herbicide treated subplots, is in agreement with the results reported by Kuo and Jellum (2002) who found that various winter cover crops, including rye, ryegrass (*Lolium multiflorum*

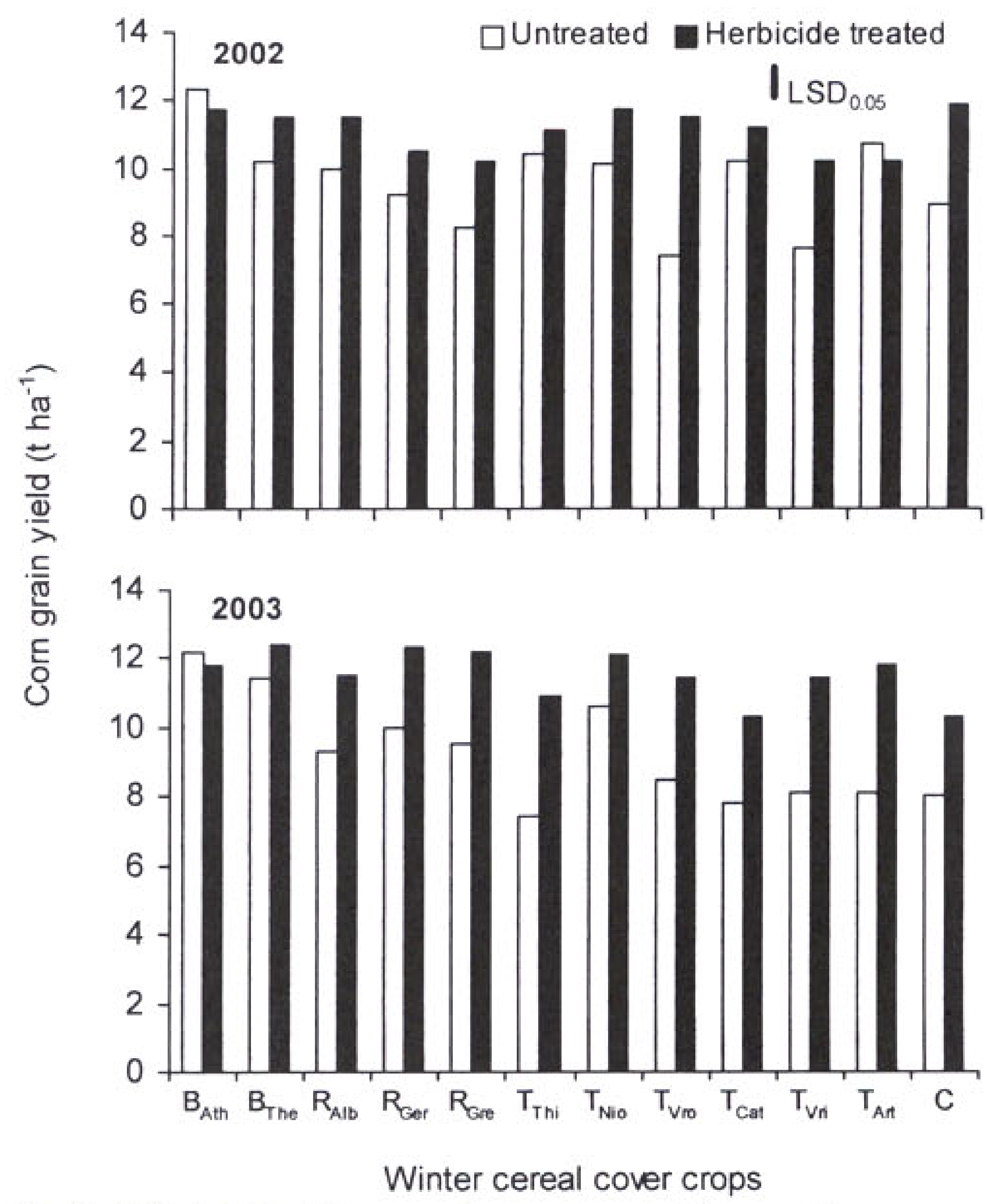

Fig. 9. Effect of 11 winter cereal cover crop mulches and two grasses (barnyardgrass and bristly foxtail) on corn grain yield. B_{Ath}, barley Athinaida; B_{The}, barley Thessaloniki; R_{Alb}, rye Albania; R_{Ger}, rye Germany; R_{Gre}, rye Greece; T_{Thi}, triticale Thisvi; T_{Nio}, triticale Niovi; T_{Vro}, triticale Vronti; T_{Cat}, triticale Catria; T_{Vri}, triticale Vrito; T_{Art}, triticale Artemis; C, control.

Lam.), and vetch, did not affect corn yield. In addition, Reddy (2001) found that cover crop residues did not affect significantly soybean yield in plots where weeds were controlled by post-applied herbicides. On the contrary, Johnson et al. (1993) found that corn population, height, and yield were reduced by hairy vetch and rye used as cover crops.

The corn yield increase in plots where barley cultivar Athinaida had incorporated is in agreement with findings of Shrestha et al. (2002) who reported that soybean yield was increased by the presence of rye and corn used as cover crops. Also, Swanton et al. (1999) found that corn yield was increased by a rye cover crop and Moore et al. (1994) reported that soybean yield of the rye and triticale mulch treatments were 69 and 91% greater, respectively, than the bare soil treatment. The different effect of barley cultivar Athinaida on corn yield, compared with those of the other winter cereals tested, could be attributed to its stronger effect on grass weed emergence and growth. Also, this fact could be related to differences on total amount and physicochemical characteristics of the allelochemicals produced by these winter cereals (Burgos et al., 1999; Burgos and Talbert, 2000).

CONCLUSIONS

The results of this study indicate clearly that some inhibitory substances are present in the winter cereals studied and specifically in barley cultivar Athinaida. These substances can affect initial growth of annual grass weeds like barnyardgrass and bristly foxtail, without having any detrimental effect on corn. This information is useful for plant breeding purposes, because a cultivar with high allelochemicals content such as Athinaida is a good candidate to enhance the allelopathic potential of other desirable barley cultivars through crossing or other genetic manipulation. Also, the high allelochemicals content and biomass would be important in choosing an appropriate cover crop for weed suppression. Moreover, these cultivars or the substances found in their extracts could be used in the future as cover crops or naturally occurring herbicides, respectively, to suppress susceptible weeds like barnyardgrass and bristly foxtail grown in tolerant crops like corn.

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