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Eric A. Nelson and George O. Kegode

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Article abstract

Biennial wormwood has become a serious weed of several crops in the northern Great Plains of the United States and Prairie Provinces of Canada. Greenhouse replacement series experiments were conducted to investigate the effects of watering regime (stressed and non-stressed) and nitrogen rate (50, 100, 150, and 200 mg $kg^{-1}$ of soil) on competition between soybean and biennial wormwood. Soybean height was reduced after 9 weeks of competition with biennial wormwood compared with soybean grown in monoculture, whereas biennial wormwood plants were taller when grown with soybean than in monoculture. The change in plant height indicated that biennial wormwood height was increased due to interspecific competition, whereas soybean height was reduced. When moisture was limited, the relative yield of biennial wormwood was greater than that of soybean, indicating that biennial wormwood was more aggressive than soybean. Soybean growth was unaffected by an increase in nitrogen rate, whereas biennial wormwood fresh weight was 30% greater when the nitrogen rate was increased from 50 to 200 mg $kg^{-1}$. Biennial wormwood aggressivity tended to increase as the nitrogen rate was increased from 50 to 200 mg $kg^{-1}$. Overall results suggest that the negative impact of biennial wormwood competition with soybeans under field conditions may increase when soil moisture is limited and nitrogen fertility is increased.

# Biennial wormwood (*Artemisia biennis*) competition with soybean (*Glycine max*)

Eric A. Nelson[1] and George O. Kegode[2]

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Biennial wormwood has become a serious weed of several crops in the northern Great Plains of the United States and Prairie Provinces of Canada. Greenhouse replacement series experiments were conducted to investigate the effects of watering regime (stressed and non-stressed) and nitrogen rate (50, 100, 150, and 200 mg $kg^{-1}$ of soil) on competition between soybean and biennial wormwood. Soybean height was reduced after 9 weeks of competition with biennial wormwood compared with soybean grown in monoculture, whereas biennial wormwood plants were taller when grown with soybean than in monoculture. The change in plant height indicated that biennial wormwood height was increased due to interspecific competition, whereas soybean height was reduced. When moisture was limited, the relative yield of biennial wormwood was greater than that of soybean, indicating that biennial wormwood was more aggressive than soybean. Soybean growth was unaffected by an increase in nitrogen rate, whereas biennial wormwood fresh weight was 30% greater when the nitrogen rate was increased from 50 to 200 mg $kg^{-1}$. Biennial wormwood aggressivity tended to increase as the nitrogen rate was increased from 50 to 200 mg $kg^{-1}$. Overall results suggest that the negative impact of biennial wormwood competition with soybeans under field conditions may increase when soil moisture is limited and nitrogen fertility is increased.

Keywords: Biennial wormwood, competition, moisture stress, nitrogen, replacement series, soybean.

**[Compétition entre l'armoise bisannuelle (*Artemisia biennis*) et le soja (*Glycine max*)]**

L'armoise bisannuelle est devenue une importante mauvaise herbe pour plusieurs cultures dans le nord des Grandes Plaines des États-Unis et dans les provinces des Prairies au Canada. Des expériences avec des séries de remplacement ont été menées en serre afin d'étudier les effets du régime d'alimentation en eau (stressant et non stressant) et de la quantité d'azote (50, 100, 150 et 200 mg $kg^{-1}$ de sol) sur la compétition entre le soja et l'armoise bisannuelle. Après 9 semaines de compétition avec l'armoise bisannuelle, la taille du soja était inférieure à celle du soja en monoculture alors que l'armoise bisannuelle était plus grande en présence de soja qu'en monoculture. Les différences dans la taille des plantes montrent que la compétition interspécifique a fait augmenter celle de l'armoise bisannuelle et diminuer celle du soja. Lorsque l'eau était un facteur limitatif, le rendement relatif de l'armoise bisannuelle était plus élevé que celui du soja, ce qui montre que l'armoise bisannuelle était plus agressive que le soja. L'augmentation de la quantité d'azote n'a pas affecté la croissance du soja. Cependant, le poids de matière fraîche de l'armoise bisannuelle était 30 % plus élevé lorsque la quantité d'azote est passée de 50 à 200 mg $kg^{-1}$. L'agressivité de l'armoise bisannuelle a eu tendance à augmenter lorsque la quantité d'azote est passée de 50 à 200 mg $kg^{-1}$. Globalement, les résultats montrent que les impacts négatifs de la compétition entre l'armoise bisannuelle et le soja, dans des conditions naturelles, peuvent s'accroître lorsque l'eau manque et que la quantité d'azote disponible augmente.

Mots clés : Armoise bisannuelle, azote, compétition, séries de remplacement, soja, stress hydrique.

1. Department of Plant Sciences, North Dakota State University, Fargo, ND 58105-5051. Current address: Harvest Land Cooperative, 710 Front Street, Morgan, MN 56266
2. Department of Plant Sciences, North Dakota State University, 166 Loftsgard Hall, Fargo, ND 58105-5051, USA; corresponding author e-mail: george.kegode@ndsu.edu

## INTRODUCTION

Soybean (*Glycine max* (L.) Merr.) has become a major oilseed crop of the northern Great Plains of the United States. Soybean production in North Dakota was estimated at 1.5 x $10^6$ ha in 2004, suggesting a 7.5 fold increase since 1990 (NDASS 2004). This increase in production area occurred partly because of the decline in wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) production, which was partly due to the increased incidence of fusarium head blight (*Fusarium graminearum* Schwabe) in the state (US GAO 1999). In addition, the Federal Agricultural Improvement and Reform Act brought several changes in the farm subsidy program in 1996 that gave farmers more freedom in choosing crops (Bierlen *et al.* 2000). The expanded soybean production area has provided new niches for invasive/problematic weed species such as biennial wormwood.

Biennial wormwood (*Artemisia biennis* Willd.) is native to the northwestern United States and western Canada (Munz and Keck 1968; Thomas 1961), but populations have been found everywhere within the United States except in the southeastern states (Hall and Clements 1923). Biennial wormwood has been a problem in soybean and dry edible bean (*Phaseolus vulgaris* L.) fields of North Dakota, South Dakota and Minnesota for the past several yr (Kegode and Christoffers 2003). Biennial wormwood has been expanding its habitat range and has recently been placed on a "Weeds to Watch" list by several scientists of the North Central United States (Johnson *et al.* 2004).

Biennial wormwood exhibits both an annual and a biennial life cycle (Fernald 1950). Mature biennial wormwood is a tall, woody plant and a prolific seed producer (Mahoney and Kegode 2004; Stevens 1932). Biennial wormwood can grow over 3 m tall and produces thick stems, up to 5 cm in diam, that may impede crop harvest. Season-long competition from 10 biennial wormwood plants $m^{-2}$ decreased the yield of soybean seeded in 76-cm rows by 44% (Nelson and Kegode 2000). This reduction in soybean yield was presumed to be both attributable to direct competition with biennial wormwood and impeded harvest.

Biennial wormwood infestations have increased due to a combination of factors. Many herbicides used for broadleaf weed control in soybean and dry bean do not provide acceptable biennial wormwood control. Biennial wormwood is frequently misidentified as common ragweed (*Ambrosia artemisiifolia* L.), and herbicides used to control common ragweed do not control it (Kegode and Christoffers 2003).

Time of weed germination and emergence relative to crop emergence sets in place the dynamics of competition. Germination of biennial wormwood has not been well-characterized. Freshly harvested biennial wormwood seeds appear to germinate best when seeds are exposed to a maximum temperature of 37°C with a diurnal temperature fluctuation of 24°C or greater (Kegode *et al.* 2004). Biennial wormwood field emergence usually occurs in mid- to late June in eastern North Dakota (Kegode and Ciernia 2003) and seedlings that emerge late are capable of producing numerous seeds (Mahoney and Kegode 2004). Fronning and Kegode (2004) reported, however, that biennial wormwood emergence can vary depending on soil type. In that study, emergence of biennial wormwood occurred in late April in a sandy loam soil, late May to early June in a loam soil, and late June in a silty clay soil.

The hazards arising from weeds in any plant production system may be viewed at two levels: reduced absolute yield and reduced value of that product (Cousens and Mortimer 1995). Typically, crop yield loss will bear a proportional relationship to the abundance of weeds and the duration and severity of interference with the crop (Cousens 1985). The outcome of interference is determined by the time of emergence of weeds and crops in relation to diminishing resources such as soil moisture and nitrogen.

Soil moisture conditions can greatly affect seedling growth and the competitive ability of weeds (Wiese and Vandiver 1970). Ogg *et al.* (1994) reported that pea (*Pisum sativum* L.) was sensitive to soil water content, and its ability to compete with mayweed chamomile (*Anthemis cotula* L.) was impaired by drought stress.

Soil nitrogen level is an important factor in weed crop interference (Okafor and De Datta 1976). Changes in dry matter production of perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) following nitrogen application were associated with an increase in aggressivity of perennial ryegrass rather than a nitrogen-related reduction in the relative growth of white clover (Martin and Field 1984).

Weed competition studies are based on binary species mixtures, and different indices are used to evaluate competition. For instance, the relative yield total (RYT) index consists of the addition of crop and weed relative yields and indicates resource complementarity (de Witt 1960; Radosevich *et al.* 1997), whereas the aggressivity index includes the effect of competition on both the crop and weed and indicates competitive ability (Radosevich *et al.* 1997). In the following experiments, the aspect of reduction of yield was evaluated in the greenhouse under various conditions. The objectives of this research were to determine the effect of watering regime and nitrogen level on competition between biennial wormwood and soybean.

## MATERIALS AND METHODS

### General greenhouse methodology

Two greenhouse experiments were conducted to investigate the effects of watering regime and soil nitrogen concentration on competition between biennial wormwood and soybean. Both experiments used a replacement series (De Wit 1960) with five soybean:biennial wormwood ratios of 4:0, 3:1, 2:2, 1:3 and 0:4 in a randomized complete block design. Biennial wormwood seeds harvested from plants that had grown in a soybean field near Fergus Falls, MN, in 1999 and 'Traill' soybean were used for both experiments.

Soybean and biennial wormwood were pregerminated to ensure uniformity of plants at the commencement of competition. Biennial wormwood seeds were placed on the soil surface in 5-cm-diam by 8-cm-deep peat pots filled with a 75:25 mixture of Foldahl loamy fine sand (sandy over loamy, mixed aquic haploboroll):potting mixture (70-80% Canadian sphagnum peat moss, perlite, dolomitic limestone (for pH adjustment), gypsum, and wetting agent) and watered to field capacity. Clear plastic was placed over the pots for 3 d to increase the humidity and temperature for uniform biennial wormwood germination and emergence (Mahoney and Kegode 2004). This method of incubation resulted in relatively fast and uniform biennial wormwood emergence. Soybean was seeded directly into the 28-cm-diam by 30-cm-deep pots filled with 10 kg of soil-potting mixture as outlined above, at twice the number needed to conduct the experiment, and thinned to the desired density 4 d after emergence.

Upon seedling emergence, the clear plastic was removed and biennial wormwood seedlings were watered as needed. Biennial wormwood seedlings were thinned to three similar-sized plants per pot 1 wk after emergence and transplanted into the pots containing soybean when both species were 5 cm tall. Because emergence time for biennial wormwood was longer than for soybean, biennial wormwood was seeded 2 wk before soybean to achieve uniform height of both species at time of transplanting. To minimize the transplant shock, the soil surrounding the roots of the biennial wormwood seedlings was maintained intact during transplanting. Upon transplanting of biennial wormwood, the pots were watered and fertilized as dictated by the protocol for each study and placed in a greenhouse set at a temperature of 25 ± 2°C with a 16-h photoperiod under natural sunlight supplemented with high-pressure mercury halide lamps (230 µmol $m^{-2}$ $s^{-1}$). The pots were randomly moved around periodically to avoid position effects within the greenhouse.

## Effect of watering regime on competition

A two-factor replacement series was conducted in the greenhouse to evaluate the effect of watering regime and plant ratio on competition between soybean and biennial wormwood. The five soybean:biennial wormwood plant ratios described previously were used and the watering regimes were non-stressed, in which pots were watered to field capacity daily, and water-stressed, in which water was withheld until 75% of all plants showed signs of wilting. In this experiment, watering was accomplished by adding water until pots leaked from below. The experiment was configured as a completely randomized design with four replicates and was repeated three times.

Soybean and biennial wormwood were allowed to compete for 9 wk before plant measurements were made. Field studies indicated that a significant reduction in soybean yield occurred following 6 wk of competition with biennial wormwood (Nelson and Kegode 2000). Consequently, the 9 wk period of competition in this study was arbitrarily chosen to encompass the time frame in which soybean could compete with biennial wormwood and show a loss in productivity. After 9 wk, plants were removed from pots, their roots washed using water from a low pressure hose spray, and whole plant fresh weight, shoot and root dry weights and shoot length were measured. Soybean and biennial wormwood plants were dried at 55°C for 7 d prior to obtaining dry weights.

## Effect of nitrogen rate on competition

A two-factor replacement series experiment was conducted to evaluate the effect of nitrogen concentration and plant ratio on competition between soybean and biennial wormwood. There were five soybean: biennial wormwood ratios and four nitrogen levels of 50, 100, 150 and 200 mg $kg^{-1}$ soil. Nitrogen rates were chosen based on the amount of nitrogen already in the soil and adjusting upwards in even increments. The desired nitrogen rates were obtained by adding 0, 500, 1000 and 1500 mg of nitrogen as ammonium nitrate immediately following transplanting of biennial wormwood seedlings. Each pot contained 10 kg of Sioux sandy loam (sandy-skeletal mixed udorthentic haploboroll) which contained 50 mg $kg^{-1}$ nitrogen as indicated by soil tests. The soil tests indicated that soil phosphorus and potassium levels were adequate for soybean growth: soil pH was 6.5 and soil organic matter was 3.5%. Pots were sealed so as to prevent nutrient loss and water was added cautiously each time so as to avoid flooding the pots. The experiment was configured as a completely randomized design with three replications and was repeated.

All pots, after planting, were watered to field capacity daily. The two species were allowed to compete for 9 wk before plants were removed from the pots. Their roots were washed using water from a low pressure hose spray and measurements were taken, including soybean and biennial wormwood whole plant fresh and dry weight, shoot length from the soil surface, and shoot, root, and leaf dry weight. Soybean and biennial wormwood plants were dried as previously described.

## Statistical analysis

Prior to data analysis, relative yield, relative yield total and aggressivity indices were determined from some of the growth parameters measured. Relative yield (RY) of each species was calculated according to Radosevich *et al.* (1997) as follows:

$$RY_a = Y_{mix} / Y_{mono}$$

where $RY_a$ = relative yield of species (a), $Y_{mix}$ = yield for species (a) in mixture, and $Y_{mono}$ = yield of species (a) in monoculture.

Relative yield total (RYT) describes how species use resources in relation to each other (Radosevich *et al.* 1997) and was determined by adding the relative yields of biennial wormwood and soybean for each plant ratio. Values of RYT near 1 indicate that the same resources are being used, while RYT < 1 indicates mutual antagonism and RYT > 1 suggests avoidance or symbiosis. When RYT = 1, differences between the two species are still possible. For example, one species may be more aggressive than the other and contribute more than expected to the total yield, while the other contributes less than expected. This unequal contribution indicates an interaction between species for a common resource and that one species gains more than the other.

Aggressivity defines the relative success of two species in using resources and provides a means to evaluate interference among an array of species (Radosevich *et al.* 1997). Biennial wormwood aggressivity indices were calculated by subtracting the soybean relative yield from the biennial wormwood relative yield, and the indices can range from 1 to -1. When two species are grown in a 50:50 mixture, the aggressivity value will equal zero if the two species are competing equally. The aggressivity value for biennial wormwood will be 0.5 when it outnumbers soybean by a 3:1 ratio when both species are competing proportionately. Likewise, the value for biennial wormwood will be -0.5 when the two species are competing proportionately in a 3:1 ratio of soybean: biennial wormwood.

Analysis of variance procedures were conducted on data from these two experiments and means were separated using Fisher's protected LSD test at the 0.05 significance level. The main effects for both greenhouse experiments were fixed effects. No treatments by experiment interactions were present; therefore, data were combined over repetitions in time for each experiment. Student's *t*-test at $P \leq 0.05$ was used to determine whether RYTs differed significantly from unity (1.0) and whether aggressivity indices differed significantly from zero (equal competitors). Dry weight data were used in our discussion primarily, though where there were no differences, fresh weight data that showed significant differences were used appropriately.

## RESULTS AND DISCUSSION

### Effect of watering regime on competition

Soybean plants were 14% shorter when only one biennial wormwood plant was growing in competition with three soybean plants compared with soybean grown alone and were 25% shorter when three biennial wormwood plants were growing with one soybean plant (Table 1). Inversely, biennial wormwood plants were tallest when grown with two (2:2 ratio) or three (3:1 ratio) soybean plants. Biennial wormwood plants reached a maximum height of 62 cm when one plant grew with three soybean plants. Biennial wormwood height in monoculture was 11% shorter compared with biennial wormwood growing in mixture at the 3:1 soybean:biennial wormwood ratio. This indicated that biennial wormwood height was decreased more by intraspecific competition than by interspecific competition with soybean.

Based on dry plant weights, aggressivity of biennial wormwood at a 2:2 plant ratio was 0.27 and not significantly different from 0, which indicated that biennial wormwood was equally as aggressive as soybean at plant ratios containing at least 50% biennial wormwood (Table 1). As expected, biennial wormwood was more aggressive than soybean when there were three biennial wormwood plants in the mixture. Watering regime, however, did not affect the aggressivity of biennial wormwood relative to soybean. In contrast, Ogg *et al.* (1994) reported that decreases in available moisture increased the aggressivity of mayweed chamomile (*Anthemis cotula* L.) relative to pea (*Pisum sativum* L.).

Biennial wormwood under non-stressed conditions contributed 12% more than expected to the relative fresh weight yield at the 3:1 soybean:biennial wormwood ratio (Table 2). All other plant ratios in the non-stressed watering regime provided the expected relative yields of biennial wormwood. When moisture was limited, biennial wormwood contributed 16, 25 and 13% more than expected to the relative yield at the 3:1, 2:2 and 1:3 soybean:biennial wormwood ratios, respectively. The increase in biennial wormwood relative yield indicates that biennial wormwood gained more of the common resources than soybean, particularly when the two species were moisture-stressed.

The RYT of soybean plus biennial wormwood, competing at the five plant ratios, was not statistically different from 1.0 when based on total plant dry weight (Fig. 1A), which indicates that the same resources were being used equally by the two species. Similarly, mayweed chamomile and pea competed alike at both low and high water levels (Ogg *et al.* 1994). Even though under moisture stress conditions mayweed chamomile was more aggressive

**Table 1. Soybean and biennial wormwood plant height and biennial wormwood aggressivity indices as influenced by five soybean:biennial wormwood ratios after 9 wk of competition in a replacement series experiment, averaged over stressed and non-stressed watering regimes**

| Soybean:biennial wormwood ratio | Plant height (cm) | | Biennial wormwood aggressivity[a,b] |
|---|---|---|---|
| | Soybean | Biennial wormwood | |
| 4:0 | 44 | – | – |
| 3:1 | 38 | 62 | -0.29 |
| 2:2 | 37 | 60 | 0.27 |
| 1:3 | 33 | 53 | 0.55* |
| 0:4 | - | 55 | 1.00* |
| LSD (0.05) | 4 | 6 | 0.09 |

[a] Aggressivity based on plant dry weights. Aggressivity defines the relative success of the two species in using resources, where zero signifies the two species are competing equally, -1 signifies complete dominance of soybean, and +1 signifies complete dominance of biennial wormwood.

[b] Values followed by an asterisk are significantly greater than zero according to a one-tailed *t*-test.

**Table 2. Influence of soybean:biennial wormwood ratio and stressed and non-stressed watering regime on the relative yield of biennial wormwood, based on fresh weight after 9 wk of competition with soybean in a replacement series experiment**

| Soybean:biennial wormwood ratio | Predicted relative yield | Relative yield[a] Watering regime[b] Non-stressed | Stressed |
|---|---|---|---|
| 4:0 | – | – | – |
| 3:1 | 0.25 | 0.37 | 0.41 |
| 2:2 | 0.50 | 0.56 | 0.75 |
| 1:3 | 0.75 | 0.77 | 0.88 |
| 0:4 | 1.00 | 1.00 | 1.00 |
| LSD (0.05)[c] | | ---------- 0.08 ---------- | |

[a] Relative yield calculated as the individual plant fresh weight in mixture as a proportion of the corresponding individual plant fresh weight in monoculture.
[b] Non-stressed treatments were watered to field capacity daily. Stressed treatments were watered to field capacity each time 75% of plants showed signs of wilting.
[c] Least significant difference between watering regimes and among plant ratios at 5% probability.

than pea, the RYTs of pea and mayweed chamomile were similar in varying moisture levels regardless of planting arrangement.

Biennial wormwood relative yield at the 2:2 ratio was greater than expected based on shoot dry weight (data not shown), and at the 3:1 and 2:2 soybean: biennial wormwood ratios when based on total dry weight (Fig. 1A). Conversely, soybean at the 2:2 plant ratio contributed less total dry weight than would be expected. Uneven contribution to the RYT indicates that biennial wormwood is gaining more of the common resources than soybean. At the 2:2 plant ratio, biennial wormwood contributed 12% more to the RYT than soybean; this is the plant ratio where both species would be contributing equally if not for biennial wormwood being more aggressive than soybean when moisture was limited.

The differential response of the two species to soil moisture stress suggests that under field conditions biennial wormwood would have the competitive edge during periods when moisture was most limited. These data also imply that biennial wormwood may thrive best when growing with crops, such as soybean, that do not compete aggressively when soil moisture is limited, and for which there are few options for biennial wormwood control.

## Effect of nitrogen rate on competition

Soybean fresh weight was reduced by 16% at the 1:3 soybean:biennial wormwood ratio compared with soybean in monoculture (Table 3). Similarly, soybean root dry weight was reduced by 17 and 21% in the 1:3 and 2:2 soybean:biennial wormwood ratios, respectively, compared with soybean in monoculture. The low soybean fresh and dry root weights at high biennial wormwood ratios are indicative of interspecific competition between soybean and biennial wormwood.

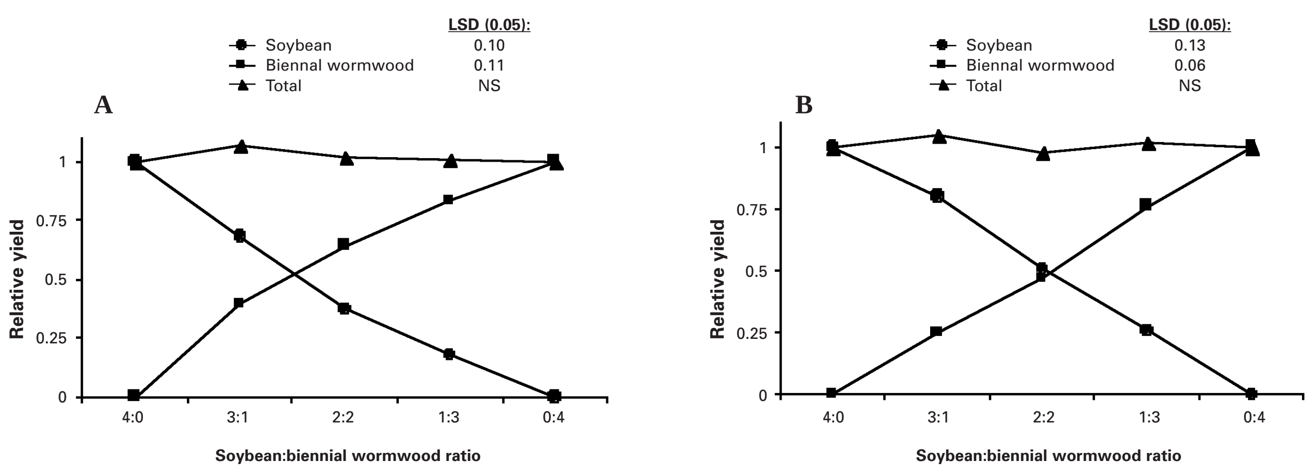


**Figure 1. Influence of soybean:biennial wormwood ratio on soybean, biennial wormwood and total yield expressed as relative yield based on dry weight after 9 wk of competition in a replacement series experiment averaged across A) non-stressed and stressed watering regimes, and B) four nitrogen rates.** LSD (0.05) values compare relative yields among plant ratios within a species.

**Table 3. Influence of soybean:biennial wormwood ratio on soybean total fresh and root dry weights averaged across four nitrogen rates, and influence of plant ratio and nitrogen rates on biennial wormwood leaf dry weight after 9 wk of competition in a replacement series experiment**

| Soybean:biennial wormwood ratio | Soybean | | Biennial wormwood leaf dry weight (g per plant) | | | |
|---|---|---|---|---|---|---|
| | | | Soil nitrogen (mg kg$^{-1}$ soil) | | | |
| | Total fresh weight (g per plant) | Root dry weight (g per plant) | 50 | 100 | 150 | 200 |
| 4:0 | 49 | 2.4 | – | – | – | – |
| 3:1 | 50 | 2.4 | 4.4 | 4.9 | 6.1 | 6.0 |
| 2:2 | 43 | 1.9 | 3.9 | 5.0 | 5.4 | 6.1 |
| 1:3 | 41 | 2.0 | 4.1 | 5.2 | 6.2 | 5.9 |
| 0:4 | – | – | 4.2 | 5.4 | 5.7 | 6.1 |
| LSD (0.05) | 7 | 0.3 | ------------------------ 0.4[a] ------------------------ | | | |

[a] Least significant difference among soil nitrogen rates and plant ratios at 5% probability.

Biennial wormwood leaf dry weight increased as the nitrogen rate increased for all soybean:biennial wormwood ratios (Table 3). Biennial wormwood leaf dry weight in monoculture was greatest at the 150 and 200 mg kg$^{-1}$ nitrogen rates, and lowest with 50 mg kg$^{-1}$ nitrogen. Biennial wormwood leaf dry weight for both the 50 and 150 mg kg$^{-1}$ nitrogen rates decreased as the plant ratio changed from a 3:1 to a 2:2 soybean:biennial wormwood ratio, and increased at the 150 mg kg$^{-1}$ nitrogen rate as the plant ratio changed from 2:2 to 1:3.

Biennial wormwood plant height and total dry weight increased as nitrogen increased from 50 to 150 mg kg$^{-1}$ but did not increase further when nitrogen increased to 200 mg kg$^{-1}$ (Table 4). Biennial wormwood plant height with 150 mg kg$^{-1}$ of nitrogen increased by 7% and total dry matter increased by 28% when compared with plants grown in soil with 50 mg kg$^{-1}$ nitrogen. Similarly, mayweed chamomile, in competition with pea, grew much larger when nitrogen was added compared with no added nitrogen (Ogg *et al.* 1994). The actual consequence of biennial wormwood's response to added nitrogen may be more evident in the field than in the greenhouse because soybean growth ceases before that of biennial wormwood. Biennial wormwood in soybean fields grows substantially while soybean senesces and dries down, and is therefore able to interfere with soybean harvest.

The aggressivity index of biennial wormwood increased both as the nitrogen rate increased and as the plant ratio changed from a soybean monoculture to a biennial wormwood monoculture (Table 4). The aggressivity index of biennial wormwood for the 2:2 plant ratio at 50 mg kg$^{-1}$ nitrogen was zero and increased to 0.12 at the 100 mg kg$^{-1}$ nitrogen rate. Biennial wormwood aggressivity did not increase any further as the nitrogen rate was increased to 150 or

**Table 4. Influence of nitrogen rate on biennial wormwood plant height and total plant dry weight averaged over plant ratios, and nitrogen rate and soybean:biennial wormwood ratio on biennial wormwood aggressivity after 9 wk of competition with soybean in a replacement series experiment**

| Soil nitrogen rate (mg kg$^{-1}$ soil) | Plant height[a] (cm) | Total dry weight[a] (g per plant) | Aggressivity indices[b] | | | | |
|---|---|---|---|---|---|---|---|
| | | | Soybean:biennial wormwood ratio | | | | |
| | | | 4:0 | 3:1 | 2:2 | 1:3 | 0:4 |
| 50 | 96 | 11.7 | – | -0.47 | 0.00 | 0.47* | 1.00* |
| 100 | 99 | 14.4 | – | -0.57 | 0.12* | 0.64* | 1.00* |
| 150 | 103 | 16.2 | – | -0.44 | 0.08 | 0.47* | 1.00* |
| 200 | 106 | 16.3 | – | -0.49 | 0.12* | 0.53* | 1.00* |
| LSD (0.05) | 5 | 0.9 | ---------------------------- 0.08[c] ---------------------------- | | | | |

[a] Biennial wormwood plant heights and total dry weights were averaged over the five plant ratios because there was no significant interaction between plant ratio with either plant height or total dry weight.
[b] Aggressivity indices define the relative success of the two species in using resources, where zero signifies the two species are competing equally, -1 signifies complete dominance of soybean, and +1 signifies complete dominance of biennial wormwood. Values followed by an asterisk are significantly greater than zero according to a one-tailed *t*-test.
[c] Least significant difference among soil nitrogen rates and plant ratios at 5% probability.

200 mg $kg^{-1}$. For the 1:3 soybean:biennial wormwood ratio, biennial wormwood aggressivity index increased from 0.47 at 50 mg $kg^{-1}$ nitrogen to 0.64 at 100 mg $kg^{-1}$, but decreased thereafter to 0.53 at 200 mg $kg^{-1}$. Aggressivity indices for biennial wormwood were statistically greater than zero for the 2:2 plant ratio at 100 and 200 mg $kg^{-1}$, and for the 1:3 plant ratio at all nitrogen rates, which, as expected, indicates that biennial wormwood was competing more aggressively than soybean.

Soybean relative yield at the 2:2 plant ratio decreased from 0.5 to 0.4 as the nitrogen rate increased from 50 to 200 mg $kg^{-1}$ (Table 5). Theoretically, the reduced aggressivity of soybean could have been due to hindering of soybean by an increasing nitrogen rate. However, an adverse response to nitrogen seems unlikely because the contribution of soybean at the 3:1 soybean:biennial wormwood ratio to the RYT increased from 0.73 to 0.85 as the nitrogen rate was increased from 50 to 200 mg $kg^{-1}$. Most likely, this response was due to increased biennial wormwood growth at the higher nitrogen rates since biennial wormwood aggressivity at the 2:2 plant ratio increased as the nitrogen rate increased (Table 4).

The RYTs were nearly equal when based on dry shoot and total dry weights, which indicates that soybean and biennial wormwood competed equally for water and nitrogen (Fig. 1B). When soybean plants comprise 75% of the plant ratio, soybean would be expected to contribute 0.75 to the RYT. In this case, soybean contributed 0.8 when based on both dry shoot and total dry weights, which was not statistically greater than 0.75 (Fig. 1B). For the relative yields of biennial wormwood based on dry shoot and total dry weights, the values were not statistically different from what would be expected for even competition. The difference from expected contribution to actual contribution was similar at all ratios and not statistically significant.

When the RYT was calculated for dry shoot and total plant dry weight, all values were statistically equal to 1.0 (Fig. 1B), which indicates that nitrogen and other common resources were being used similarly by both species. These findings are similar to those of Ogg *et al.* (1994) who reported that pea and mayweed chamomile did not compete for nitrogen.

Biennial wormwood infestations under field conditions are usually greater than those used in this study and therefore competitive effects are likely more intense than what was observed. For example, Fronning and Kegode (2004) reported biennial wormwood densities between 84 and 194 plants $m^{-2}$ in soybean weed management studies at three locations. Nelson and Kegode (2000) reported that season-long competition from 10 biennial wormwood plants $m^{-2}$ reduced harvestable soybean yields by 44%. Part of the yield loss was probably due to harvesting inefficiency since at harvest, biennial wormwood was 137 cm tall compared to 66-cm-tall soybean. Furthermore, biennial wormwood plants had stems that averaged 3 cm in diam, which impeded harvest.

Soybean and biennial wormwood compete similarly for water and nitrogen and therefore high densities of biennial wormwood will likely lead to a large reduction in soybean yield. In our study, biennial wormwood and soybean were seeded so they emerged within the same time period. However, in North Dakota fields, soybean is seeded in mid- to late May and emerges in late May to early June whereas biennial wormwood typically emerges in late June to early July (Kegode and Ciernia 2003). Apart from causing harvesting inefficiency due to late maturation of biennial wormwood (Kegode and Christoffers 2003), it is unclear how competitive late-emerging biennial wormwood plants can be in the presence of soybean.

Allelopathic interference by biennial wormwood on soybean is a possibility since biennial wormwood leaf, stem and root biomass added to soil caused 14, 10 and 32% reduction in fresh weight of soybean, respectively, after 14 d (Ciernia and Kegode 2003; Kegode and Ciernia 2005). Biennial wormwood allelopathy appeared to increase as the plant increased in size, which might explain why this species emerges late and yet competes with crops to cause yield loss. Future research needs to address the aggressivity of late-emerging biennial wormwood plants with respect to allelopathic interference.

**Table 5. Influence of soybean:biennial wormwood ratio and nitrogen rate on soybean relative yield based on fresh weight after 9 wk of competition with biennial wormwood in a replacement series experiment**

| Soybean:biennial wormwood ratio | Relative yield[a] Soil nitrogen rate (mg $kg^{-1}$ soil) 50 | 100 | 150 | 200 |
|---|---|---|---|---|
| 4:0 | 1.00 | 1.00 | 1.00 | 1.00 |
| 3:1 | 0.73 | 0.83 | 0.69 | 0.85 |
| 2:2 | 0.50 | 0.44 | 0.42 | 0.40 |
| 1:3 | 0.22 | 0.22 | 0.20 | 0.21 |
| 0:4 | – | – | – | – |
| LSD (0.05)[b] | ---------------------------- 0.06 -------------------------- | | | |

[a] Relative yield describes how species use resources in relation to each other.

[b] Least significant difference among soil nitrogen rates and plant ratios at 5% probability.

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