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Infestation of European corn borer, *Ostrinia nubilalis*, in Midwestern USA fields with herbaceous borders

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Abstract

Three years (2000–2002) of field studies were conducted in mid-Missouri, USA, to assess the impact of various compositions of herbaceous field borders on populations of the European corn borer, *Ostrinia nubilalis*. Border treatments of: (1) a mixture of warm-season grasses and legumes, (2) a mixture of cool-season grasses and legumes, (3) tall fescue alone, and (4) a corn border control were planted around plots of field corn. Percent stalks infested with European corn borer and number and length of larval tunnels in stalks were analyzed. Warm-season vegetation-bordered corn had consistently lower percent stalks infested than corn bordered by cool-season vegetation, tall fescue or a corn control. The results indicate that the adoption of field border programs such as CP33 will have little or no impact on European corn borer management.

Keywords: Quail; Conservation border; Field margins; Vegetation buffer; *Zea mays*

1. Introduction

The USDA National Conservation Buffer Initiative promotes CRP goals mainly through the promotion of field border plantings or buffer strips. The recently announced (October 2004) conservation reserve program CP33, *Habitat Buffers for Upland Birds*, provides incentives for establishing borders in and around cropland that provide food and shelter to grassland birds, particularly the northern bobwhite, *Colinus virginianus* L. Bobwhite populations have declined range wide by 3% annually since 1966, mainly because of habitat loss (Brennan, 1991; Sauer et al., 2004). The European community has faced similar game bird losses, and the Department for Environment, Food and Rural Affairs, UK, promotes an Environmental Stewardship program very similar to the USDA Conservation Reserve Program. Set-asides, grass field margins, and conservation headlands (edges of cereal crop fields that are sprayed selectively to allow native plants and their associated insects to develop) are all used to promote farmland birds such as the gray partridge, *Perdix perdix* L., by providing nest sites and increasing food resources (Sotherton et al., 1993; Vickery et al., 2002).

Despite the availability of cost sharing for vegetation buffers, farmers in the United States have not adopted this conservation approach in any great numbers (Lovell and Sullivan, 2006). Demonstration of the positive aspects of buffers for the environment and wildlife is not enough; the lack of negative impacts on crop production must be demonstrated before conservation programs become a popular option for farmers.

The European corn borer, *Ostrinia nubilalis* Hübner, is a serious pest of corn and other crops throughout the Midwest United States, costing farmers more than 1.85 billion dollars annually in crop loss and pest management outlays (Calvin, 1995; Ostlie et al., 1997).

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While considered primarily a pest of corn, the European corn borer has a wide host range and will attack almost any herbaceous species with a large, robust stalk for the larvae to enter (Hudson et al., 1989; Bourguet et al., 2000). The moth also utilizes grassy areas for mating (Caffrey and Worthley, 1927; Pedigo, 1989). Consequently, farmers may be hesitant to adopt field border programs where the border might act as a reservoir for this pest species.

The impact of four border treatments on European corn borer prevalence and damage to adjacent cornfields was examined over a 3-year period. Our specific objectives were to determine naturally occurring second generation European corn borer: (1) stalk infestation rates; (2) number of larval tunnels; (3) average larval tunnel length in corn adjacent to borders of a cool-season grass/legume mix, a warm-season grass/legume mix, tall fescue, and corn (control).

2. Methods and materials

Three years of field studies were conducted in central Missouri at Reform Conservation Area, Callaway County, MO, USA. Ameren Union Electric owns the 2500+ ha Reform Conservation Area, which is a mixture of forest, grasslands and croplands, and the Missouri Department of Conservation is the lead management agency for the area. Mexico silt loam is the dominant soil in the area.

Twelve fields in the Reform Conservation Area were identified as blocks. The fields ranged in size from 2 to 16 ha. A corn–soybean rotation was utilized, with six fields in corn, *Zea mays* L., and six fields in soybeans, *Glycine max* (L.) Merr., each year. The experiment was a repeated incomplete block design: every combination of two treatments was applied to the six blocks, resulting in three replications per treatment for each year of the study. The corn planted was Pioneer® 33G26 (Pioneer Hi-Bred International Inc., Johnston, IA), a non-transgenic variety commonly used by producers in the area. This variety has a European corn borer resistance rating of five, moderately resistant (9: excellent resistance, 1: poor resistance).

In March 2000, fields were disced and fertilized (120/60/60 NPK). Corn was planted 14–22 April 2000 in six fields. In 2001, corn was planted 22–25 April in fields that were in soybeans in 2000. Corn was planted 18–26 April 2002, in the same fields as 2000. Soybeans were planted in the alternate six fields in May of each year. Corn rows were planted on 76 cm centers and the corn was managed under conventional agronomic practices (e.g., tillage, fertilization, herbicide application, cultivation, and harvest), but without application of insecticides.

Field borders 9.1 m wide were established in spring 2000 adjacent to the cropland prior to crop planting. This is the minimum width for enrollment in CP33. The border areas were originally part of the crop fields and, in March 2000, were sprayed with herbicide (Roundup®, Monsanto Company, St. Louis, MO, USA) and were disced prior to planting. The four border treatments were: (1) a cool-season grass/legume mixture—including orchard grass (*Dactylis glomerata* L.), timothy (*Phleum pratense* L.) and red clover (*Trifolium pratense* L.), (2) a single cool-season grass—tall fescue (*Festuca arundinacea* Schreb.), (3) a warm-season grass/legume mixture—little bluestem (*Andropogon scoparius* Michx.), side-oats grama (*Bouteloua curtipendula* Michx.) and lespedeza (*Lespedeza stipulacea* Maxim.), and (4) a control—the unsprayed (no insecticide) crop, either corn or soybean to match the field crop, corn in this study.

A Brillion planter was used to plant fescue and cool-season grass mixtures on 7 April 2000. Growing conditions in the spring of 2000 were poor, and initial weed competition was strong because of a drought. Cool-season grass and fescue borders were mowed 1 June, 2 August, 17 August, and 12 September 2000, to reduce weed pressure and promote seeded mixture growth. Cool-season borders were over seeded with the original seed mixture on 22 September 2000, to promote establishment. Cool-season and fescue borders were mowed once in the following years, 11 July 2001, and 20 June 2002. Warm-season grass plantings were sown 4–5 May 2000. A tank mix of Plateau® and Roundup® herbicide was applied at labeled rate as a pre-emergent on the newly planted warm-season grass field borders on 14 May 2000, to promote establishment by reducing competition from weeds.

Weed pressure in cool-season vegetation and tall fescue borders was high initially, but declined to insignificant levels over the 3 years of the study. Warm-season vegetation borders retained a significant weedy component throughout the study. The two primary weed species in all of the borders were giant foxtail, *Setaria faberi* Herrm., and common ragweed, *Ambrosia artemisiifolia* L. Several other weed species were also present, including cheatgrass, *Bromus tectorum* L., shattercane, *Sorghum bicolor* (L.) Moench, and yellow nutsedge, *Cyperus esculentus* L.

The vegetation was characterized in the field borders during two sampling periods (May and July) each year to determine establishment success and to assess the habitat. Starting at a point selected randomly along the outside edge of each border, two 1 m^2 quadrants were located within the borders, the first 2 m from the outside edge of the border and the second 6 m from the outside edge of the border. A 0.25 m × 0.25 m frame was placed randomly within each quadrant and vegetation was removed from within 1 cm of the ground surface to obtain a total of 0.125 m^2 of material from both quadrants combined for analysis. The plant material was sorted into general categories (grasses, forbs, and legumes), dried, and weighed to determine biomass.

An initial survey for the presence of second generation European corn borer egg masses was conducted in late July 2000, by examining plants in rows approximately 3 and 9 m from the crop–border interface, but no eggs were observed. Consequently, stalks were split to assess larval damage in September in the nearest 3 and 9 m rows into the field from

Table 1
Biomass (dry weight, g/0.125 m^2) of vegetation in four different borders surrounding cornfields over 3 years

Border treatment	Date	Grass	Forbs	Legumes
Corn	00 May	3.1	6.2	0.0
	00 July	85.0	15.0	0.0
	01 May	3.1	0.0	0.0
	01 July	40.4	0.0	0.0
	02 May	0.0	0.0	0.0
	02 July	196.9	1.2	0.0
Cool-season vegetation	00 May	23.3	6.1	1.6
	00 July	56.0	1.1	0.7
	01 May	50.5	4.5	14.5
	01 July	15.9	0.5	2.8
	02 May	82.0	0.1	0.0
	02 July	56.5	0.1	0.0
Tall fescue	00 May	7.5	2.1	0.0
	00 July	61.1	8.6	0.0
	01 May	47.8	1.7	0.7
	01 July	32.9	1.1	0.0
	02 May	77.2	0.0	0.0
	02 July	58.7	0.1	0.0
Warm-season vegetation	00 May	0.0	0.0	0.0
	00 July	2.0	0.0	0.0
	01 May	17.1	7.5	0.7
	01 July	12.8	5.0	1.5
	02 May	24.6	10.8	1.5
	02 July	74.7	77.1	17.8

Vegetation samples were sorted into one of three broad categories: grasses, forbs, or legumes.

the border/crop interface. In 2001 and 2002, samples from 18 m into the field were added. Twenty corn stalks (from two rows) in 2000 and 10 corn stalks (from one row) in 2001 and 2002 at each distance were split to determine European corn borer infestation. Presence/absence of European corn borer larvae, and number and length of larval tunnels (if present) were recorded.

Data were analyzed with SAS PROC MIXED tests (Systat Ver 6.0, Cary, SC) as a repeated incomplete block design with distance into field treated as a subplot. The random effects in the MIXED procedure were field within year and year by field within border treatment, providing the correct variance estimates and error terms for the test statistics. A simple F-test indicated that variances were similar across years and allowed for pooling data across years. The appropriate interactions, treatments, and distance into fields were compared with least squares means.

3. Results

In 2000, growing conditions in the spring were poor because of drought, and initial weed competition in the borders was strong. Weed pressure in cool-season vegetation and tall fescue borders declined substantially over the 3 years of the study, while warm-season vegetation borders retained a significant weedy component, including the continued presence of *Conyza* sp., *Veronia* sp., *Helianthus* sp., and *Solanum* sp. Consequently, warm-season vegetation borders were highly diversified in contrast to the other three border treatments, which were dominated by one or a few herbaceous species. Border compositions became more distinct from one another over time. Herbaceous biomass in the borders varied with individual species response to environmental factors, management activities such as mowing, and with crop growth dynamics (Table 1).

Although not always significant, stalk infestation of warm-season vegetation-bordered corn was always two to three times less than that of cornfields surrounded by the other three border treatments. In 2000, the percent stalks infested by European corn borer larvae were significantly lower in warm-season vegetation-bordered cornfields compared to corn-bordered cornfields (Table 2). In 2001

Table 2
Stalk infestation by European corn borer for cornfields with different surrounding borders

Year	Border treatment	N	% Stalk infestation[a]	Mean tunnel length (cm)[a]	Mean # tunnels per stalk[a]
2000	Corn	3	21.7 ± 12.9 a	1.02 ± 0.77 a	0.27 ± 0.18 a
	Cool-season vegetation	3	14.7 ± 17.2 ab	0.40 ± 0.40 a	0.18 ± 0.19 ab
	Tall fescue	3	16.7 ± 7.0 ab	0.50 ± 0.23 a	0.20 ± 0.08 ab
	Warm-season vegetation	3	5.2 ± 6.4 b	0.16 ± 0.22 b	0.05 ± 0.06 b
2001	Corn	3	26.7 ± 17.3 a	1.06 ± 0.76 ab	0.31 ± 0.21 a
	Cool-season vegetation	3	24.4 ± 8.8 a	1.10 ± 0.56 ab	0.31 ± 0.11 a
	Tall fescue	3	24.4 ± 19.4 a	1.34 ± 1.44 a	0.40 ± 0.36 a
	Warm-season vegetation	3	12.2 ± 6.7 b	0.41 ± 0.29 b	0.13 ± 0.09 b
2002	Corn	3	35.6 ± 20.1 a	1.89 ± 1.35 ab	0.48 ± 0.34 a
	Cool-season vegetation	3	38.9 ± 19.0 a	2.10 ± 1.38 ab	0.54 ± 0.36 a
	Tall fescue	3	37.8 ± 26.8 a	2.46 ± 2.17 a	0.54 ± 0.47 a
	Warm-season vegetation	3	21.1 ± 13.6 a	1.01 ± 0.66 b	0.23 ± 0.14 a
All years	Corn	9	28.8 ± 17.7 a	1.36 ± 1.07 a	0.36 ± 0.27 a
	Cool-season vegetation	9	27.4 ± 17.2 a	1.29 ± 1.13 ab	0.37 ± 0.28 a
	Tall fescue	9	27.5 ± 21.6 a	1.55 ± 1.73 a	0.40 ± 0.38 a
	Warm-season vegetation	9	13.8 ± 11.4 b	0.57 ± 0.57 b	0.15 ± 0.13 b

[a] Mean ± S.D. Border treatments with different letters differed significantly from one another at $P < 0.05$.

and when all years were combined, stalk infestation by European corn borer larvae was significantly lower in warm-season vegetation-bordered cornfields compared to the others (Table 2). Infestation rates were not significantly different among treatments in 2002, a severe drought year. Stalk infestation rates in cool-season vegetation-, tall fescue-, and corn-bordered cornfields did not differ from one another in any year.

European corn borer larval tunnel length and tunnel number followed the stalk infestation pattern closely, with both measurements consistently lower in warm-season vegetation-bordered corn than in the other three bordered-cornfield combinations. Larval mean tunnel length was significantly shorter in warm-season vegetation-bordered cornfields compared to the other three treatments in 2000 (Table 2). In 2001 and 2002, larval tunnel length was significantly shorter in warm-season vegetation-bordered cornfields compared to tall fescue-bordered cornfields. When all years were combined, larval tunnel length in warm-season vegetation-bordered cornfields was significantly shorter that corn- and tall fescue-bordered cornfields. European corn borer larval tunnel length did not differ significantly among corn-, cool-season vegetation-, and tall fescue-bordered cornfields for any of the years (Table 2).

The number of European corn borer larval tunnels was significantly lower in warm-season vegetation-bordered cornfields than in corn-bordered cornfields in 2000 (Table 2). In 2001 and when years were combined, there were fewer tunnels in warm-season vegetation-bordered cornfields than in the other three border-cornfield combinations. There were no differences in tunnel number among treatments in 2002. The number of European corn borer tunnels did not differ significantly among corn-, cool-season vegetation-, and tall fescue-bordered cornfields for any of the years (Table 2).

A different pattern emerged for stalk infestation by European corn borer larvae when distance into the cornfield was examined. Although there was a general pattern of increased stalk infestation at 18 m from the border compared to 3 and 9 m from the border, distance from the crop–border interface was not a significant factor in stalk infestation by European corn borer for corn-, warm-season vegetation- or cool-season vegetation-bordered corn for any of the years or the years combined (Table 3). Tall fescue, on the other hand, showed a significant pattern of increasing percent stalk infestation the further from the border into the field one went for all 3 years and overall; stalk infestation was two to three times lower 3 m from the tall fescue border than further into the cornfields. On a yearly basis, stalk infestation at 3 m from the tall fescue border was significantly lower than at the 9 and 18 m distances in every case except 2002, where it was not significantly different from the 9 m distance but was different from the 18 m distance. Number and length of European corn borer tunnels exhibited a similar pattern, with significant differences among distances from the border for tall fescue-bordered corn only. On the other hand, warm-season vegetation-bordered corn hosted a significantly lower percent stalk infestation by European corn borer at the 9 and 18 m distances when compared to the other bordered-corn treatments at those distances (Table 3). At 3 m from the border, stalk infestation was not significantly different among border treatments, although both tall fescue- and warm-season vegetation-bordered corn harbored about half the number of European corn borer larvae than did corn- or cool-season vegetation-bordered corn.

4. Discussion

A 15% point decrease (ca. 14% versus ca. 29%) in stalk infestation by European corn borer was observed when cornfields were bordered by a warm-season vegetation mixture compared to cornfields bordered by a cool-season vegetation mixture, tall fescue, or corn. Warm-season vegetation was the most difficult border treatment to establish, and was very weedy in the first year of the study. Weed pressure decreased but remained a significant component over the following 2 years, and the weeds in the warm-season vegetation borders may have influenced the European corn borer's presence in the adjacent cornfields.

The border treatments did not follow CP33 guidelines faithfully because the borders were planted prior to the creation of the guidelines; i.e., CP33 requires a native mix of little bluestem and side-oats grama, plus 10 additional native forb species, while our initial planted warm-season grass mixture consisted only of little bluestem, side-oats grama and lespedeza. The experimental borders, however, followed CP33 guidelines for Missouri in that they were the proper

Table 3
Percent stalk infestation by European corn borer by distance from border and by surrounding border over 3 years

Border[a]	Distance from border (m)[b]		
	3	9	18
Corn	26.7 ± 19.8 aA	25.6 ± 13.3 aA	36.7 ± 20.7 aA
Cool-season vegetation	26.5 ± 15.9 aA	23.3 ± 14.8 aA	35.0 ± 24.3 aA
Tall fescue	13.3 ± 11.3 aA	28.9 ± 19.2 bA	46.7 ± 23.3 bA
Warm-season vegetation	10.0 ± 11.2 aA	11.3 ± 6.3 aB	23.3 ± 13.7 aB

[a] European corn borer infestation measured into the field from the border/field interface.
[b] Mean ± S.D. Small letters: infestation rates in rows with different letters differed significantly from one another at $P < 0.05$. Capital letters: infestation rates in columns with different letters differed significantly from one another at $P < 0.05$.

width, contained the major plant components required, and the perimeters of crop fields were lined with hedgerows of trees or shrubs. The presence of a significant weedy component in the warm-season vegetation borders diversified the plant community to a level similar to what is required by CP33, and although the weeds in the border treatment may have contributed to the reduction in corn border infestation in the adjacent cornfields, similar common weed species would likely be present in a border following strict CP33 guidelines, as well.

That corn borer infestation decreased as the insect approached the tall fescue borders is interesting because the European corn borer uses grassy areas for mating, and has a wide host range—it can develop in many plants with robust enough stalks (Caffrey and Worthley, 1927; Hudson et al., 1989; Pedigo, 1989; Bourguet et al., 2000). The intuitive conclusion is that grassy borders would act as a reservoir and would promote stalk infestation by the European corn borer, and not, as in this study, lower corn borer infestation for warm-season vegetation-bordered cornfields, or decrease stalk infestation rates the closer the European corn borer got to the tall fescue border.

The European corn borer may have been present in lower numbers in warm-season vegetation-bordered corn for a number of reasons. The border may have acted as a 'trap crop' or refuge, with the insect more attracted to, and more likely to remain in, the vegetation in the border than in the corn. This is not likely because the evidence indicates that corn is the preferred host for the European corn borer (Losey et al., 2001). Also, Martel et al. (2003) has shown that populations of European corn borer from corn are genetically isolated from European corn borers on other sympatric host plants, making it unlikely corn borers that would normally be in the cornfields were moving into the borders. The mechanisms behind the lower infestation rate in corn near the fescue border were not investigated in this study.

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References

Bourguet, D., Bethenod, M.T., Trouve, C., Viard, F., 2000. Host-plant diversity of the European corn borer *Ostrinia nubilalis*: what value for sustainable transgenic insecticidal Bt maize? Proc. Roy. Soc. London, Ser. B: Biol. Sci. 267, 1177–1184.

Brennan, L.A., 1991. How can we reverse the northern bobwhite decline? Wildl. Soc. Bull. 19, 544–555.

Caffrey, D.J., Worthley, L.H., 1927. A progress report on the investigations of the European corn borer. USDA Bull. 1476.

Calvin, D.D., 1995. Economic benefits of transgenic corn hybrids for European corn borer management in the United States. A Report to the Monsanto Company.

Hudson, M., LeRoux, E.J., Harcourt, D.G., 1989. Seventy years of European corn borer (*Ostrinia nubilalis*) research in North America. Agric. Zool. Rev. 3, 53–96.

Losey, J.E., Calvin, D.D., Carter, M.E., Mason, C.E., 2001. Evaluation of noncorn host plants as a refuge in a resistance management program for European corn borer (Lepidoptera: Crambidae) on Bt-corn. Environ. Entomol. 30, 728–735.

Lovell, S.T., Sullivan, W.C., 2006. Environmental benefits of conservation buffers in the United States: evidence, promise, and open questions. Agric. Ecosyst. Environ. 112, 249–260.

Martel, C., Rejasse, A., Rousset, F., Bethenod, M.T., Bourguet, D., 2003. Host-plant-associated genetic differentiation in Northern French populations of the European corn borer. Heredity 90, 141–149.

Ostlie, K.R., Hutchinson, W.D., Hellmich, R.L., 1997. Bt corn and European corn borer. North Central Regional Publication 602, University of Minnesota, St. Paul.

Pedigo, L.P., 1989. Entomology and Pest Management. McMillan Publishing Company, New York.

Sauer, J.R., Hines, J.E., Fallon, J., 2004. The North American Breeding Bird Survey, Results and Analysis 1966–2003. Version 2004.1. USGS Patuxent Wildlife Research Center, Laurel, MD.

Sotherton, N.W., Robertson, P.A., Dowell, S.D., 1993. Manipulating pesticide use to increase the production of wild gamebirds in Britain. In: Quail III: National Quail Symposium. Kansas Department of Wildlife and Parks, Pratt, KS, pp. 91–102.

Vickery, J., Carter, N., Fuller, R.J., 2002. The potential value of managed cereal field margins as foraging habitats for farmland birds in the UK. Agric. Ecosyst. Environ. 89, 41–52.