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Potential Corn Yield Losses from Weeds in North America

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Crop losses from weed interference have a significant effect on net returns for producers. Herein, potential corn yield loss because of weed interference across the primary corn-producing regions of the United States and Canada are documented. Yield-loss estimates were determined from comparative, quantitative observations of corn yields between nontreated and treatments providing greater than 95% weed control in studies conducted from 2007 to 2013. Researchers from each state and province provided data from replicated, small-plot studies from at least 3 and up to 10 individual comparisons per year, which were then averaged within a year, and then averaged over the seven years. The resulting percent yield-loss values were used to determine potential total corn yield loss in t ha^{-1} and bu acre^{-1} based on average corn yield for each state or province, as well as corn commodity price for each year as summarized by USDA-NASS (2014) and Statistics Canada (2015). Averaged across the seven years, weed interference in corn in the United States and Canada caused an average of 50% yield loss, which equates to a loss of 148 million tonnes of corn valued at over U.S.$26.7 billion annually.

Nomenclature: Corn, *Zea mays* L.

Key words: Best management practices, crop losses, economic loss, herbicides, weeds, weed management, USA, Canada

Las pérdidas de cultivos debido a la interferencia de malezas tiene un efecto económico significativo en la rentabilidad neta de los productores. Aquí se documentan las pérdidas potenciales en el rendimiento de maíz debido a la interferencia de malezas a lo largo de las principales regiones productoras de maíz de los Estados Unidos y de Canada. Los estimados de pérdida de rendimiento fueron determinadas a partir de observaciones cuantitativas comparativas entre el rendimiento de maíz sin tratamiento y con tratamientos que brindaran un control de malezas superior al 95% en estudios realizados desde 2007 hasta 2013. Los investigadores de cada estado y provincia proveyeron datos de estudios replicados con parcelas pequeñas con al menos 3 y hasta 10 comparaciones por año, las cuales fueron promediadas dentro de cada año, y luego promediadas por los siete años. El porcentaje de pérdida de rendimiento resultante fue usado para determinar la pérdida total de rendimiento del maíz en t ha^{-1} y bu acre^{-1} con base en el promedio de rendimiento del maíz para cada estado o provincia, y el precio del maíz para cada año según USDA-NASS (2014) y Statistics Canada (2015). Al promediar los siete años, la interferencia de malezas en el maíz en Estados Unidos y Canada causó en promedio un 52% de pérdida de rendimiento, lo que equivale a una pérdida de 142 millones de toneladas de maíz valorado en más de U.S.$26,722 millones anualmente.

Corn is of huge economic importance to agriculture in the United States and Canada, where nearly 262,000,000 and 10,700,000 tonnes are produced on approximately 35,400,000 and 1,400,000 ha, with an approximate farm gate value of $51,000,000,000 and $2,000,000,000, respectively (Statistics Canada 2015; USDA-NASS 2014). The United States ranks first in the world, with 35.5% of global corn production, whereas Canada ranks 11th with 1.2% of corn production in 2011 (FAO Stat 2012; Statistics Canada 2015).

Weeds are the most serious threat to corn production annually in the United States and Canada, causing billions of dollars in economic losses because of lower yields because of resource competition (nutrients, moisture, and light), cost of weed control, interference with efficiency of harvesting operations, and contamination of harvested grain (Chandler et al. 1984). Herbicides are the primary method of weed management in corn

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production across the United States and Canada. The U.S. Department of Agriculture–National Agricultural Statistics Service (USDA-NASS) (2014) report that the average amount of herbicides applied to corn has remained relatively constant at 2.2 to 2.8 kg ha^{-1} since 2000.

Crop improvement through plant breeding has increased corn yield substantially during the past 20 yr (Oerke 2006). Agronomists continue to develop and promote best-management practices, including diverse crop rotations, reduced tillage, precision seeding (optimal seeding date, seed spacing, seeding depth, seeding rates), optimal fertilization rates, and timing (including micronutrients), and management of other pests, such as insects and diseases (Oerke 2006). Practices specifically developed for weed management include the release of new herbicides and new herbicide-resistant hybrids, such as glyphosate-resistant (Roundup Ready, Monsanto) and glufosinate-resistant (LibertyLink, Bayer, CropScience) corn. The adoption of glyphosate-resistant corn resulted in a shift in practices to POST applications, encouraged no-tillage crop production, and shifted the species composition of weed populations. The competiveness of corn with weeds has increased, in part, because of increased seedling vigor, more rapid early growth, narrower row spacing, and increased seeding rate. There is a lack of recent yield-loss data for the effect of weeds on corn yield since these production practices have changed.

Yield-loss from weeds in corn has historically been difficult to estimate, largely because of a lack of quantitative data (Walker 1983, 1987). The generation of data required to estimate losses from weeds in corn is time consuming and expensive; losses can vary from season to season, can potentially be confounded by other abiotic and biotic stresses, and can vary considerably across different regions within the United States and Canada (Harker 2001; Walker 1987).

Few nonsurvey estimates of yield losses in corn from weeds were published in the 20th and early 21st century. The first effort to estimate yield loss from weeds on a global basis was published by the USDA in 1927 (ultimately, multiple publications were produced by the USDA, as summarized by Cramer [1967]). The Weed Science Society of America (WSSA) Weed Loss Committee generated reports in 1984 (Chandler et al.), 1992 (Bridges), and 1993 (Swanton et al.), which summarized crop losses from weeds across the United States and Canada. These reports estimated corn yield loss from weeds as great as 18% in United States and 12% in Canada (Bridges 1992; Chandler et al. 1984; Swanton et al. 1993). In recent years, Oerke et al. (1994) and Oerke (2006) summarized estimates of losses from pests on a global basis and reported that actual losses from weeds in corn exceed 10% worldwide, ranging from 5% in western Europe up to 19% in western Africa after the implementation of weed-management tactics.

Previous reports have provided limited information on the comparative losses from weeds across geographic regions and crops within these regions of the United States and Canada. The Weed Loss Committee of the WSSA is updating previous surveys on the estimated crop losses from weeds that were published in 1984 (Chandler et al.), and in 1992 to 1993 (Bridges 1992; Swanton et al. 1993). These earlier reports mostly relied on percentage yield reduction estimates provided by research or extension personnel and comments by producers in each state or province. Few reports on crop losses from weeds have focused on the comparative observations of corn yields between the weedy control and plots with greater than 95% weed control. Determining potential corn yield loss from weed interference and the associated potential economic loss would provide a useful knowledge base that could be used to direct research goals in the area of integrated weed management strategies for corn production across the United States and Canada (Swanton et al. 1993).

The objective of this WSSA Weed Loss Committee study is unique because it estimates corn yield loss from weed interference in the absence of any weed management tactics from replicated, small-plot studies across North America. Comparative observations of corn yields between nontreated and treated plots with greater than 95% weed control were obtained from studies conducted from 2007 to 2013 from the primary corn-producing regions in the United States and Canada. Then, the economic effect of weed management in corn in the United States and Canada was reported.

Materials and Methods

Requests for data were sent to research and/or extension weed science specialists from various states and provinces (listed in Table 1) in 2013 and 2014. Each specialist was asked to provide results from up

Table 1. Potential average corn production and value losses from weeds for each state or province that provided data for the period of 2007 to 2013. Harvested hectares (and acres) and yield data (tonnes or bushels) obtained from USDA-NASS (2014) and AAFC (2015).

Region/state or province	Harvested	Average yield	Yield loss	Potential loss in production	Potential loss in value (at \$194.48 t^{-1} or \$4.94 bu^{-1})
	ha × 1,000 (ac × 1,000)	t ha^{-1} (bu ac^{-1})	%	t × 1,000 (bu × 1,000)	U.S.\$ × 1,000
Northeast					
Delaware	70 (172)	8.2 (130.7)	42.1	241 (9,479)	46,841
Pennsylvania	390 (964)	8.1 (129.4)	55.5	1,676 (65,977)	312,669
Appalachian					
Kentucky	526 (1300)	8.3 (132.9)	83.0	3,866 (152,193)	728,540
Tennessee	298 (736)	7.7 (123.0)	29.1	669 (26,319)	134,761
North Carolina	346 (854)	6.5 (104.1)	43.6	994 (39,129)	189,276
Lake states					
Michigan	896 (2,214)	9.0 (142.9)	55.8	4,481 (176,420)	871,766
Minnesota	3,104 (7,669)	10.2 (163.1)	52.6	16,716 (658,064)	3,251,777
Wisconsin	1,264 (3,123)	9.1 (144.3)	47.3	5,414 (213,126)	1,053,147
Eastern Canada					
Ontario	820 (2,027)	9.5 (151.9)	51.4	4,018 (158,188)	781,450
Corn Belt					
Illinois	4,949 (12,229)	10.1 (160.7)	50.7	25,303 (996,129)	4,922,303
Indiana	2,407 (5,949)	9.5 (152.0)	58.6	13,469 (530,239)	2,620,136
Iowa	5,408 (13,364)	10.4 (166.1)	39.9	22,520 (886,566)	4,380,904
Missouri	1,238 (3,059)	7.9 (126.4)	73.7	7,238 (284,936)	1,407,990
Ohio	1,373 (3,393)	9.7 (154.3)	60.2	8,001 (314,979)	1,556,446
Northern Plains					
North Dakota	1,005 (2,484)	7.4 (117.7)	51.3	3,811 (150,020)	741,311
South Dakota	1,959 (4,841)	8.2 (130.1)	48.0	7,680 (302,347)	1,494,027
Nebraska	3,683 (9,100)	9.8 (155.6)	52.4	20,825 (819,834)	4,051,151
Kansas	996 (2,462)	4.6 (89.1)	46.3	2,580 (101,567)	501,886
Mountain					
Montana	17 (43)	8.2 (131.1)	43.2	62 (2,460)	12,158
Southeast					
Mississippi	308 (761)	9.2 (145.9)	18	535 (21,077)	121,071
Georgia	140 (346)	9.6 (152.4)	41	526 (20,692)	98,671
Arkansas	225 (556)	10.1 (160.6)	10	260 (10,592)	58,141

to 10 individual studies conducted within a year during the period of 2007 to 2013 on weed control in corn. Data were also obtained from weed-control research reports published online for several states and provinces.

Information requested included *weedy yield*, the average corn yield from the untreated weedy plot (yield using local agronomic practices to promote optimal corn yield but no weed management tactics); and *weed-free yield*, the average yield from weed-control plots with greater than 95% control for each weed species (yield using local agronomic practices to promote optimal corn yield and excellent weed control).

Potential yield loss (YL), as a percentage, was determined for each individual study, then averaged within a year and averaged across the 7 yr for each state or province:

$$\text{Potential YL\%} = [(\text{Weed-free yield} - \text{Weedy yield})/\text{Weed-free yield}] \times 100 \qquad [1]$$

State- and province-level data for total corn hectarage and acreage harvested, average corn yield in tonnes per hectare, and total production and yearly average commodity prices were obtained from USDA-NASS (2014) and Agriculture and Agri-Food Canada (AAFC) (AAFC 2015) reports.

The economic loss was weighted by the amount of corn production within each state or province. The potential monetary loss was calculated for each

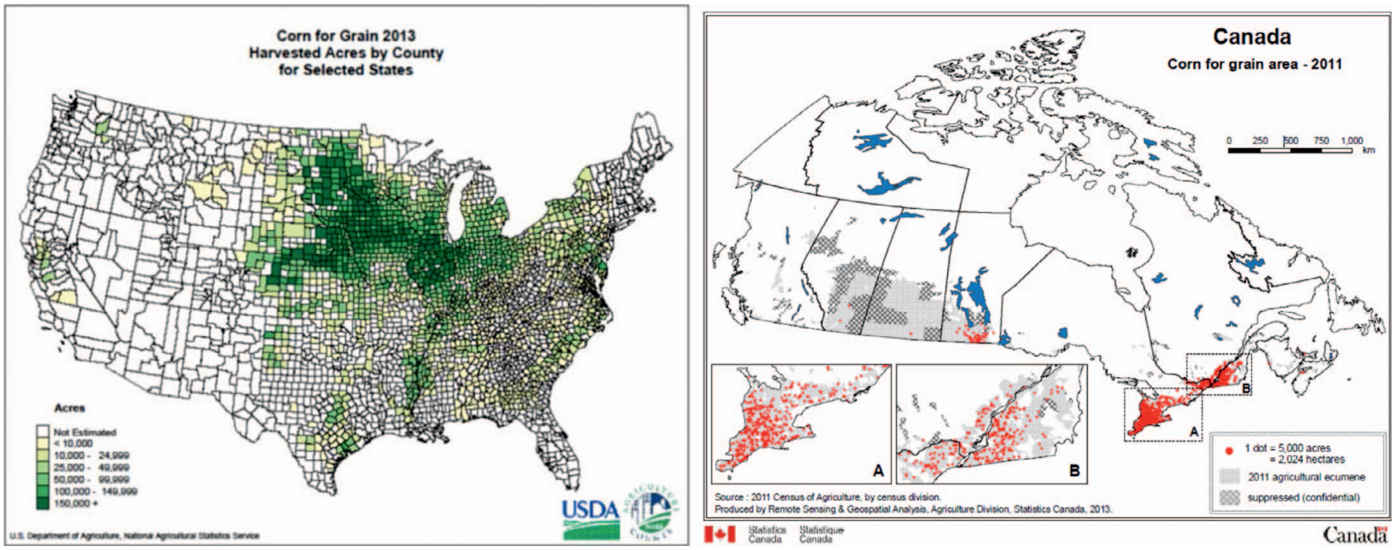

Figure 1. Distribution of corn hectares (acres) harvested for grain in the United States (2013) and in Canada (2011). Images and data from USDA-NASS (2014) and Statistics Canada (2015), respectively. (Color for this figure is available in the online version of this article.)

region as the product of the estimated quantity of corn loss times the average corn price for 2007 to 2013. Average corn price for the period of 2007 to 2013 was U.S.\$194.48 tonnes^{-1}, which was used to determine potential loss in value from weed interference (AAFC 2015; USDA-NASS 2014).

Results and Discussion

Data collected in this study represent those states and provinces that produce greater than 90% of field corn grown in the United States and Canada (Figure 1). Survey results from states and provinces were grouped into regions similar to the grouping used by Chandler et al. (1984), Bridges (1992), and Swanton et al. (1993) in previous surveys of crop losses from weeds in North America (Table 1). Table 1 summarizes data points during the 7-yr period from 21 U.S. states and the province of Ontario, Canada.

Across the United States and Canada, potential corn yield loss from weed interference was 50% when no weed-management tactics were implemented (Table 1). There was no consistent trend for potential corn-yield loss based on geography of those states reporting. In the United States, potential corn yield loss from weed interference in the absence of weed-control measures were an average of 48.8, 51.9, 51.9, 56.6, 49.5, 43.2, and 23.0% in the northeast, Appalachian, lake, Corn Belt, Northern Plains, mountain, and southeast states, respectively.

Based on individual states, potential corn loss ranged from 10 to 83% for Arkansas and Kentucky, respectively. The potential value of economic loss ranged from \$47 to \$4,923 million U.S. dollars for Delaware and Illinois, respectively (Table 1). In eastern Canada, where most Canadian corn is produced, losses from weeds, when local agronomic practices were used to promote optimal corn yields but no weed management tactics were used, were 51.4%, which equates to potential corn-production loss of approximately 4,000,000 tonnes, valued at nearly \$778,000,000 (Table 1).

This WSSA Weed Loss Committee study provided quantitative data on the potential corn-yield loss if North American corn producers did not employ any weed-management tactics, and the reported potential loss is much greater than earlier reports by the WSSA Weed Loss Committee. Chandler et al. (1984) reported an estimated 8 to 18% corn-yield loss across the United States and 3 to 12% corn-yield loss across Canada from weeds, whereas Bridges (1992) reported an estimated 1 to 15% corn-yield loss from weeds across the United States when best-management practices were used, which increased to 10 to 60% corn-yield loss with no herbicidal weed control. Swanton et al. (1993) estimated that weeds reduce corn yield by 5% or 10 million bushels, with a value of \$24 million in

Table 2. Potential total corn losses in production tonnes (and bushels) and value (U.S.$) from weeds for the United States based on 2012 Census data from USDA-NASS (2014) and 2011 Census data from Statistics Canada (2015).

Country	Corn, ha (ac)	Total production	Value ($194.48 t^{-1} or $4.94 bu^{-1})	Potential loss in production (50.3% YL)	Potential loss in value
	t × 1,000 (bu × 1,000)		U.S.$ × 1,000	t × 1,000 (bu × 1,000)	U.S.$ × 1,000
United States					
Dryland	30,187,111 (74,593,976)	262,482 (10,333,410)	51,047,499	132,028 (5,198,620)	25,676,892
Irrigated	5,187,693 (12,819,069)				
Canada	1,434,099 (3,543,735)	10,689 (420,805)	2,078,797	5,376 (211,702)	1,045,635
Total	36,808,903 (90,956,780)	273,171 (10,754,215)	53,126,296	137,405 (5,410,322)	26,722,527

[a] Abbreviation: YL, yield loss.

eastern Canada. More recently, Oerke (2006) estimated that, on a global basis, potential losses from weeds in corn exceeded 40%, and actual losses exceeded 10% of the estimated 890 million tonnes total global production (Oerke 2006).

This report from the Weed Loss Committee of the WSSA is unique because the potential corn-yield loss estimates are based on quantitative data from weed-management studies conducted across the primary corn-producing regions of the United States and Canada. In each of the studies, all weeds were removed before seeding corn with a burndown herbicide application in no-till studies and tillage in conventional-tillage studies. Thus, the potential corn-yield loss was from interference by weeds that emerged at, or after, the time of corn emergence. This study concluded that, in the absence of any weed-management tactics, corn yield can be potentially reduced from weed interference by 50% or approximately U.S.$26.7 billion annually in United States and Canada (Table 2). More than one-half of corn production and value across North America would potentially be lost if weeds are left uncontrolled. These data further emphasize the importance of weed management in corn production and the need for continued weed science research to develop long-term, sustainable, integrated weed-management systems that are tailored to the various corn-producing regions of the United States and Canada.

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