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Potential spring canola yield losses due to weeds in Canada and the United States

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Abstract

Weeds represent one of the most important biotic threats to agricultural plant health, and the potential global impact of weeds on crop yields is similar to that of all other pests (animal pests and pathogens) combined. Canola is the most-grown crop in Canada based on seeded area and generates on average Can$29.9 billion in economic activity each year. The objective of this report, sponsored by the Weed Science Society of America Weed Loss Committee, was to provide an updated estimate of potential yield and monetary losses due to weed interference in spring canola grown in Canada and the United States. Quantitative yield data from field experiments were provided by researchers and weed science professionals in the northern Great Plains region; the major canola-producing area of North America. Overall, 89 yield loss estimates were compiled, covering the 18-yr period from 2003 to 2020. Average canola yield losses due to weed interference in Alberta, Saskatchewan, Manitoba, and North Dakota were 35%, 30%, 18%, and 28%, respectively. Potential yield losses weighted by canola harvested area averaged 30%, 28%, and 30% for Canada, the United States, and both countries combined, respectively. Therefore, unfettered weed interference in spring canola represents a potential monetary loss of Can$2.21 billion, $0.16 billion, and $2.37 billion for farmers in Canada, the United States, and both countries combined. The realization of such losses could manifest through continued selection for herbicide-resistant weeds, indicating the critical need for canola farmers to diversify resistance selection pressures by implementing proactive integrated weed management programs.

Introduction

Canola is the most-grown crop based on seeded area in Canada [considering bread wheat (*Triticum aestivum* L.) and durum wheat (*Triticum durum* Desf.) as different crops; see Statistics Canada 2022]. This important oilseed crop is grown on about one quarter of all arable land in Canada each year, making it a sizable factor in the Canadian agricultural economy. The name canola is derived from "Canadian oil" owing to its unique fatty acid profile and solid shell components developed in Canada from rapeseed in the late 1960s to 1970s (Canola Council of Canada 2022a). Canola includes seeds from the *Brassica* genus [primarily *B. napus*, but also *B. rapa* L. and *B. juncea* (L.) Czern.] that contain <2% erucic acid and <30 μmol g^{-1} of key glucosinolate compounds in the oil-free seed. Compared with traditional rapeseed, these unique traits improved both the quality of the fatty acid profile for human consumption and the palatability and nutritional quality of the seed meal for livestock feed. Today, the canola value chain in Canada, including growers, seed developers, processors, and exporters, generates Can$29.9 billion in economic activity each year (Canola Council of Canada 2022b).

Canada remains the largest producer of canola worldwide, producing on average (2015 to 2020) about 19.9 billion kg of canola seed on 8.6 million ha each year (Figure 1; Statistics Canada 2022). About 99% of canola production in Canada consists of spring *B. napus* genotypes (Canadian Grain Commission 2022) grown in the prairie provinces of Alberta, Saskatchewan, and Manitoba (Figure 2; Statistics Canada 2022). Canola is grown to a lesser extent in the United States, producing on average (2015 to 2020) about 1.4 billion kg of seed on 0.7 million ha each year (Figure 1; USDA-NASS 2022); the majority (about 86% to 96%) of which is produced in North Dakota (Figure 3; USDA-NASS 2022). While few resources differentiate between spring and winter canola production in the United States, it is estimated that >90% is spring canola based on regional production practices and recent (2020 to 2022) production statistics (U.S. Canola Association 2022). Spring canola is typically grown in the northern Great Plains, whereas winter canola is grown in the south central/southern Great Plains, and both are grown in the Pacific Northwest.

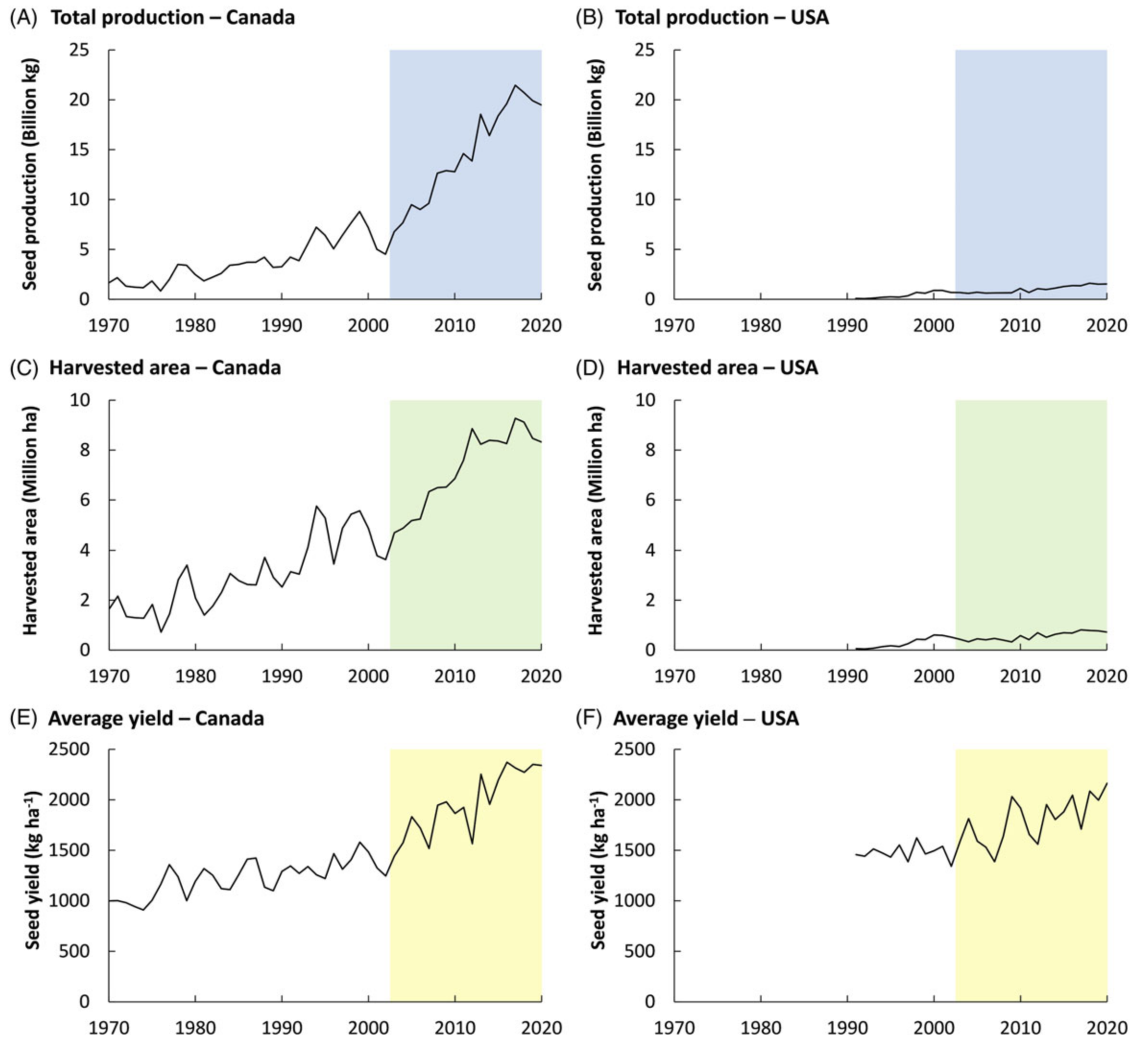

Figure 1. Spring canola annual (A, B) total production, (C, D) harvested area, and (E, F) average yield in Canada and the United States over the past 50 yr of production (1970 to 2020). Highlighted areas indicate the timeline of yield loss data compiled in the current study. Adapted from Statistics Canada (2022) and USDA-NASS (2022). Note: Production statistics represent both spring and winter canola; however, winter canola represents <1% of overall production in Canada and the United States.

Weeds represent one of the most significant biotic threats to agricultural plant health, and the potential global impact of weeds on crop yields is similar to that of all other pests (animal pests and pathogens) combined (Oerke 2006). Recent reports from the Weed Science Society of America (WSSA) Weed Loss Committee have highlighted the potential impact of weed interference on yields of several major field crops grown in North America (Dille et al. 2020; Flessner et al. 2021; Soltani et al. 2016, 2017, 2018a, 2018b). Potential yield losses due to weeds in corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.], spring wheat, winter wheat, dry bean (*Phaseolus vulgaris* L.), sugar beet (*Beta vulgaris* L.), and sorghum [*Sorghum bicolor* (L.) Moench] averaged 50%, 52%, 20%, 23%, 71%, 70%, and 47%, respectively, in their major growing regions of North America. This equates to a potential loss of about US$51.1 billion (~Can$60.5 billion) per annum in North America if weed control tactics were not implemented in these seven crops.

Understanding the potential yield and monetary losses due to weed interference is critical to quantify the return on investment for the implementation of on-farm weed control practices, and for investment in weed management research. Herbicides continue to represent the primary method of weed management in canola. Herbicide use patterns in canola changed in 1995/1996 with the introduction of herbicide resistance traits into canola cultivars followed by the rapid adoption of these technologies by farmers (Beckie et al. 2006; Brunharo et al. 2022). In 2020, the majority of canola grown in the prairie region of Canada was glufosinate-resistant (61% of insured canola land base), followed by glyphosate-resistant (28%), imidazolinone-resistant (3%), and other cultivars (<1% including glyphosate- plus glufosinate-resistant, sulfonylurea-resistant, and conventional cultivars; ~8% of cultivars with traits not specified; see Brunharo et al. 2022 and Canadian Grain Commission 2022). The introduction of herbicide resistance traits in canola resulted in either similar or improved efficacy and decreased cost of weed control, in addition to occasional yield benefits, compared with traditional herbicide regimes (Beckie et al. 2006; Harker et al. 2000; O'Donovan et al. 2006). In 1989, hybrid canola cultivars exhibiting heterosis were introduced into the marketplace. The hybrid vigor of these cultivars manifested as higher seed yield, aboveground biomass, and competitive ability compared with traditional open-pollinated canola (Beckie et al. 2008b; Harker et al. 2003; Van Deynze et al. 1992; Zand and Beckie 2002). For example, canola hybrids produced 50% greater

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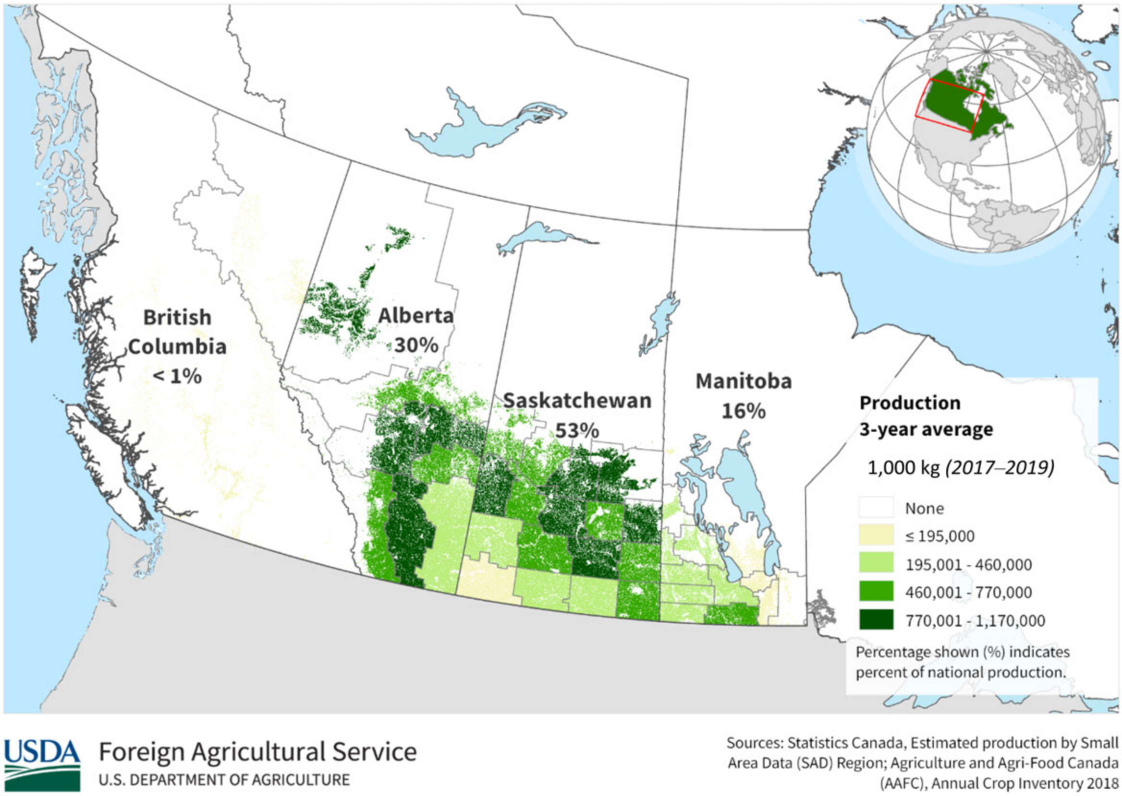

Figure 2. Map depicting the major canola-producing areas in western Canada based on kilograms of canola produced between 2017 and 2019. Image from USDA-FAS (2022). Note: Spring canola cultivars comprise essentially all canola production in western Canada.

aboveground biomass and 24% greater seed yield than open-pollinated canola (Van Deynze et al. 1992), whereas hybrid canola cultivars were twice as competitive as open-pollinated cultivars at high wild oat (*Avena fatua* L.) densities (Zand and Beckie 2002). Today, almost all canola cultivars grown in Canada are hybrids (Canadian Grains Commission 2022). While hybrid cultivars dominate spring canola production in the northern Great Plains, both hybrid and open-pollinated winter canola are grown in warmer regions of the United States (Anonymous 2018).

The rapid development of the canola industry over the past half-century represents one of the primary success stories of prairie agriculture in the northern Great Plains region. However, the sustainability of this sector is dependent on the continued efficacy of weed control practices, which is threatened by unrelenting selection for herbicide-resistant weeds in canola-growing regions. A 2014 to 2017 survey of the Canadian prairies found herbicide-resistant weeds in about 16.2 million ha (59%) of annual cropland based on field area (Beckie et al. 2020), representing a large increase from 9.9 million ha (37%) in 2007 to 2009 and 4.4 million ha (16%) in 2001 to 2003. Undoubtedly, the selection for and rapid increase of glyphosate-resistant kochia [*Bassia scoparia* (L.) A.J. Scott; see Beckie et al. 2019 and Geddes et al. 2022] was one factor, among others, contributing to the shift in herbicide resistance trait technology from the dominance of glyphosate-resistant to glufosinate-resistant canola cultivars between the 2000s and 2010s/2020s (Beckie et al. 2006; Brunharo et al. 2022; Canadian Grain Commission 2022). Therefore, it is likely that the evolution of and selection for herbicide-resistant weeds shifted herbicide use patterns in canola, and this impact will continue to grow in the absence of transformative changes to predominant weed management practices implemented by canola farmers.

Estimates of the yield and monetary losses due to weed interference in canola are warranted to inform weed management investment within the canola industry, and to help shape strategies for weed management in canola due to the increased prevalence of herbicide-resistant weeds. A 1991 WSSA Weed Loss Committee survey of expert opinion reported 11% canola yield losses due to weed interference in the Canadian prairies, equating to annual production losses of about 381 million kg of canola seed and monetary losses of Can$79 million (Swanton et al. 1993). However, 2020 canola harvested area, average yield, and total seed production in Canada and the United States were 2.8, 1.7, and 4.9 times larger, respectively, than in 1991 (Figure 1; Statistics Canada 2022; USDA-NASS 2022). The objective of this WSSA Weed Loss Committee report was to provide an updated estimate of potential yield and monetary losses due to weed interference in spring canola grown in Canada and the United States.

Materials and Methods

Weed scientists, professionals, extension specialists, and private research companies conducting research on weed management in canola were contacted and asked to provide canola yield data from experiments that included both weedy and weed-free treatments. Yield data were requested initially for a 15-yr period between 2007 and 2021, but based on data availability the search was expanded to the 18-yr period between 2003 and 2020. Other canola yield data were collected from the published scientific

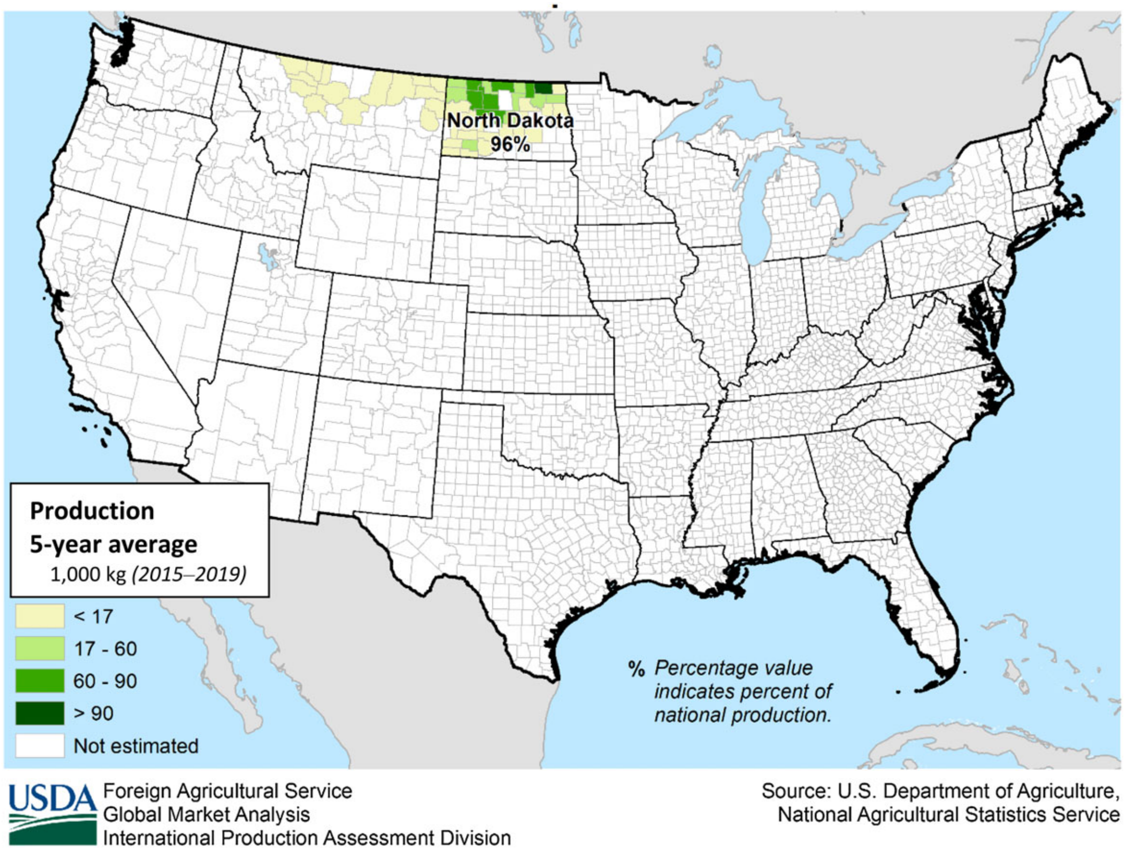

Figure 3. Map depicting the major canola producing areas in the United States based on kilograms of canola produced between 2015 and 2019. Image from USDA-FAS (2022). Note: Production metrics are undifferentiated among spring and winter canola cultivars.

literature. The methods for gathering and analyzing the quantitative yield data followed those implemented previously for other crops in recent WSSA Weed Loss Committee reports (Dille et al. 2020; Flessner et al. 2021; Soltani et al. 2016, 2017, 2018a, 2018b).

Mean yield values for season-long weedy and weed-free treatments from the same experiment and environment were required for inclusion in the data set. The weedy treatments must have had weeds controlled prior to crop planting or emergence using either tillage or nonresidual herbicide treatment. Subsequent weeds were allowed to emerge with the crop and remain in the crop for the entire growing season. The weed-free treatments were considered those with >95% visible weed control and absence of visible crop injury. All other agronomic factors were similar among the weedy and weed-free treatments and represented standard best management practices recommended for canola production in the northern Great Plains region.

Potential yield loss (*YL*%) values were calculated for each experiment and environment combination using Equation 1:

$$\text{Potential } YL\ \% = (\text{weed-free yield} - \text{weedy yield})/\text{weed-free yield} \times 100. \quad [1]$$

Yield loss values derived from each experiment were averaged within each year, then yearly yield loss values were averaged across the 18-yr period within each province or state.

Where available, province-wide/state-wide and national average canola harvested area (harvested hectares or acres), seed yield (in kilograms per hectare or bushels per acre), and total seed production (kilograms or bushels) data were compiled for the 50-yr period from 1970 to 2020 (Figure 1) using open-source databases, including Statistics Canada (2022) and USDA-NASS (2022). These data were averaged for the 18-yr period (2003 to 2020) coinciding with the yield loss data set. The average farm-gate price for canola seed (Can$552.31 per 1,000 kg) was calculated using 2013 to 2020 data reported by the Canola Council of Canada (2022c). A 10-yr (2010 to 2020) average exchange rate (1.1937 Canadian to U.S. dollars) was used to convert Canadian and U.S. currencies. Total production and farm-gate price data were used to calculate the total value of canola for each province, state, and country. Then, aggregated potential yield loss values for the corresponding jurisdiction were applied to determine the potential production and monetary losses due to weed interference. National yield and monetary losses were determined using province-wide/state-wide data weighted based on harvested canola area.

Results and Discussion

Overall, 89 yield loss estimates were obtained from Alberta, Saskatchewan, Manitoba, and North Dakota. These provinces and state together represent about 99% and 86% to 96% of canola production by weight in Canada and the United States, respectively (Figures 2 and 3; Statistics Canada 2022; USDA-NASS 2022). All

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Table 1. Spring canola annual harvested area, average yield, total production, and value, with estimated potential yield and monetary losses due to weed interference in the major canola producing provinces and states for the 18-yr period between 2003 and 2020.

Province or State	Area harvested[a,b]		Average yield		Total production		Total value	Yield loss[c]	Potential loss in production		Potential loss in value
	M ha	M ac	kg ha^{-1}	bu ac^{-1}	M kg	M bu	M Can$	%	M kg	M bu	M Can$
Alberta	2.23	5.52	2,100	37.6	4,690	208	2,590	34.6	1,620	72	896
Saskatchewan	3.65	9.01	1,770	31.6	6,440	285	3,560	30.2	1,940	86	1,080
Manitoba	1.22	3.01	1,980	35.3	2,410	106	1,330	18.1	436	19	241
Cross-provincial[d]	7.10	17.5	1,910	34.1	13,500	599	7,480	25.7	3,470	154	1,920
North Dakota	0.47	1.17	1,840	32.8	873	38.5	482	27.9	244	11	134

[a]Adapted from Statistics Canada (2022) and USDA-NASS (2022).
[b]Abbreviations: ac, acres; bu, bushels; Can$, Canadian dollars; ha, hectares; kg, kilograms; M, million.
[c]Yield loss values were determined using weedy and weed-free plots in experiments conducted within each province or state.
[d]Cross-provincial data refer to yield loss data available only as means across environments in multiple Canadian prairie provinces. These data were excluded from the tabulation of national metrics.

compiled yield loss estimates were for spring *B. napus* genotypes, the majority of which represented hybrid canola cultivars. An exception included open-pollinated canola data reported by Beckie et al. (2008a) for which yield loss values did not differ from those reported for hybrid canola.

Mean potential yield losses of spring canola due to weed interference ranged among provinces/states from 18% to 35% (Table 1). Saskatchewan accounted for about half (48%) of the canola production by harvested area (3.65 million ha) among these locations over the 18-yr period covered in the current study. During this timeframe, an average of 6.44 billion kg of canola seed was produced in Saskatchewan annually, representing an estimated total farm-gate value of Can$3.56 billion per year. With potential canola yield losses of 30% due to weed interference, this equates to a potential loss of 1.94 billion kg of canola seed for Saskatchewan farmers, equivalent to a monetary value of Can$1.08 billion. Alberta accounted for about one-third (29%) of canola production by harvested area (2.23 million ha), totaling 4.69 billion kg of canola seed and an average farm-gate value of Can$2.59 billion each year. Potential canola yield losses due to weed interference were greatest in Alberta (35%) compared with the other provinces/states. Therefore, Alberta farmers risk losing 1.62 billion kg of canola seed or about Can$0.90 billion per annum in the absence of any weed management tactics. Manitoba and North Dakota consisted of 16% (1.22 million ha) and 6% (0.47 million ha) of canola harvested area, respectively, during the study timeframe. Total canola production in Manitoba and North Dakota were 2.41 billion and 0.87 billion kg of seed, respectively, representing a farm-gate value of Can$1.33 billion and $0.48 billion per annum. These two jurisdictions also resulted in the lowest potential canola yield losses due to weed interference among the major canola-producing provinces/states. With potential canola yield losses of 18%, Manitoba farmers risk losing 0.44 billion kg of canola seed or about Can $0.24 billion per year in the absence of effective weed management. Similarly, farmers in North Dakota risk losing 0.24 billion kg of canola seed, equivalent to about Can$0.13 billion per year with potential yield losses due to weed interference of 28%.

Based on national yearly average (2003 to 2020) canola production in Canada and the United States (totaling 14.51 billion kg of canola seed and a farm-gate value of about Can$8.02 billion), unfettered weed interference in spring canola risks potential yield losses of 30%, equivalent to an annual loss of about 4.28 billion kg of canola seed or Can$2.37 billion (Table 2). About 94% of canola in the northern Great Plains region was grown in Canada, based on the 2003 to 2020 harvested area in the major canola-producing provinces/states included in the current study. Therefore, canola production in Canada averaged about 13.50 billion kg of canola seed or a farm-gate value of about Can$7.46 billion each year. With a weighted average potential yield loss of 30%, canola farmers in Canada risk losing about 4.00 billion kg of canola seed or Can $2.21 billion each year in the absence of weed management practices. On average, canola farmers in the United States grew 1.01 billion kg of canola seed each year, equivalent to Can$0.56 billion. About 28% of this is at risk of loss due to weed interference, representing a loss of 0.28 billion kg of canola seed or Can$0.16 billion annually for farmers in the United States.

Potential spring canola yield losses due to weed interference reported in the current study (30% on average; Table 2) were higher than those reported recently by the WSSA Weed Loss Committee for spring wheat (20%) and winter wheat (23%; Flessner et al. 2021), but much lower than those reported for corn (50%; Soltani et al. 2016), soybean (52%; Soltani et al. 2017), dry bean (71%; Soltani et al. 2018a), sugar beet (70%; Soltani et al. 2018b), and sorghum (47%; Dille et al. 2020). However, based on potential monetary losses for farmers in Canada and the United States, loss of effective weed control in spring canola (about Can$2.37 billion or US$1.98 billion per annum) would have a greater impact than on spring wheat (US$1.39 billion), dry bean (US$0.72 billion), sugar beet (US$1.27 billion), or sorghum (US $0.95 billion), but a lesser impact than on corn (US$26.72 billion), soybean (US$17.21 billion), or winter wheat (US$2.19 billion).

The current study represents an updated assessment of potential yield and monetary losses due to weed interference in spring canola production across its major growing areas of North America. The potential yield losses averaged across the northern Great Plains region (30%; Table 2) were greater than those (20% on average) observed across 10 canola fields in central Alberta between 1995 and 1997 (Harker 2001). Similarly, these canola yield losses were greater than those imposed by kochia monoculture (13% yield loss on average with 47 to 105 kochia plants per square meter) among five environments in southern Alberta (Geddes and Sharpe 2022). Previous 1991 estimates of canola yield loss due to weed interference based on expert opinion were 10%, 10%, and 13% in Alberta, Saskatchewan, and Manitoba, respectively; equivalent to monetary losses of Can$23 million, Can$39 million, and Can$18 million, respectively (Swanton et al. 1993). Greater yield loss estimates in the current report were likely due to our assessment using quantitative data for weedy and weed-free field plots, compared with the previous 1991 estimates, which were based on a survey of expert opinion. Weed control experiments are typically

Table 2. Spring canola annual harvested area, average yield, total production, and value, with estimated potential yield and monetary losses due to weed interference in Canada and the United States for the 18-yr period between 2003 and 2020.

Country	Harvested area[a,b]		Average yield		Total production		Total value	Weighted yield loss[c]	Potential loss in production		Potential loss in value
	M ha	M ac	kg ha^{-1}	bu ac^{-1}	M kg	M bu	M Can$	%	M kg	M bu	M Can$
Canada	7.14	17.7	1,900	33.9	13,500	599	7,460	29.6	4,000	177	2,210
United States	0.56	1.39	1,800	32.1	1,010	45	558	27.9	282	13	156
Total	7.70	19.09	1,890	33.8	14,510	644	8,018	29.5	4,282	190	2,366

[a]Adapted from Statistics Canada (2022) and USDA-NASS (2022).
[b]Abbreviations: ac, acres; bu, bushels; Can$, Canadian dollars; ha, hectares; kg, kilograms; M, million.
[c]Yield loss values were determined using weedy and weed-free plots in experiments conducted within each province or state, then weighted based on province/state-wide production area.

located in areas of fields with uniform—and often high—weed density, which undoubtedly results in greater potential yield losses. Thus, while qualitative yield loss estimates are often subject to many assumptions and uncertainties, quantitative estimates summarizing observed yield losses in weed control experiments could conceivably overestimate potential yield losses in fields with low and heterogeneous weed densities. Nevertheless, when the rapid growth of the canola industry (Figure 1) is considered along with inflation since 1991 and higher yield loss estimates, the updated monetary losses reported in the current assessment were not unexpected.

Although spring canola represents the majority of canola production (>99% by weight) in Canada and the United States (Statistics Canada 2022; U.S. Canola Association 2018; USDA-NASS 2022), it should be recognized that potential yield losses due to weed interference may differ between spring canola and winter canola cultivars. Winter cultivars represent <1% the canola grown in Canada and the United States and are grown primarily in the south-central and southern Great Plains regions. All estimates used to derive potential canola yield losses in the current assessment were based on spring canola cultivars. Since winter canola tends to yield 20% to 30% more than spring canola (U.S. Canola Association 2022), it is possible that yield losses due to weed interference in winter canola could differ from the 30% estimated for spring canola in the current study.

The current assessment highlights the critical need for implementation of proactive integrated weed management to mitigate further selection for herbicide-resistant weeds. Strategic rotation of herbicide resistance traits, mixing or layering multiple effective herbicides sites of action where possible, and timely herbicide application are important factors to mitigate weed pressure in canola (Harker et al. 2004, 2008; Martin et al. 2001). Perhaps equally as important are nonchemical weed management practices such as growing canola in a crop rotation once in three (or more) years (Cathcart et al. 2006), and planting competitive cultivars (Beckie et al. 2008a, 2008b) at higher seeding rates (Harker et al. 2003; Hosseini et al. 2006; O'Donovan 1994) early in the growing season (Bullied et al. 2006) with spring fertilization (Blackshaw et al. 2005). Competitive ability differs widely among canola and mustard [*B. juncea* (L.) Czern. or *Sinapis alba* L.] cultivars for which, in general, cultivars with rapid emergence, early growth, and tall stature result in greater weed suppression (Beckie et al. 2008b). Opportunity exists for canola breeders to exploit such diversity in the development of competitive, weed-suppressive cultivars that could become an important component of an integrated weed management system.

Past research identified effective and truly integrated strategies for weed management in canola (Blackshaw et al. 2005; Harker et al. 2003, 2016); however, further adoption of these diversified weed management programs is warranted to mitigate the continued threat and growing impact of herbicide-resistant weeds in canola production. The current study identified the potential impact of weeds on canola production and profitability in Canada and the United States. The implementation of any new on-farm weed management practice bares the imperious consideration of return on investment. Understanding the potential impact of weeds in farm fields is the foundation for these decisions. However, weed seedbanks in soil are a collective function of past management, and it is therefore imperative that weed control decisions also consider the compounding return on investment of proactive management strategies.

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