New tools for mechanical weed control in low-input dry bean (Phaseolus vulgaris) production

Authors: Stanley, K.A., and Entz, M.H.

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New tools for mechanical weed control in low-input dry bean (*Phaseolus vulgaris*) production

K.A. Stanley and M.H. Entz

Department of Plant Science, University of Manitoba, Winnipeg, MB R3T 2N2, Canada

Corresponding author: **M.H. Entz** (email: M.Entz@umanitoba.ca)

Abstract

Camera-guided narrow (15 cm)-row, inter-row cultivation, with or without the Einböck rotary weeder, reduced weed growth but had lower yield than herbicide-treated dry beans. In wide rows (60 cm), camera guidance improved finger weeder performance and mechanically weeded dry bean yields were similar to the herbicide treatment.

Key words: herbicide-free production, mechanical weed control, regenerative pulse crop production

Résumé

Le sarclage en bande étroite (15 cm) guidé par caméra, entre les rangs, avec ou sans la désherbeuse rotative Einböck, freine la croissance des adventices, mais réduit le rendement du haricot, comparativement à l'usage d'un herbicide. Quand l'espace entre les rangs est plus large (60 cm), le désherbage assisté par caméra améliore la performance du sarcleur à doigts et le rendement des haricots désherbés mécaniquement est similaire à celui obtenu avec le désherbage chimique. [Traduit par la Rédaction]

Mots-clés : agriculture sans herbicide, désherbage mécanique, culture régénérative de légumineuses

Introduction

Weed competition can reduce dry bean (*Phaseolus vulgaris* L.) yield by 85% due to poor competitive ability of dry beans with weeds (Peruzzi et al. 2017). Dry beans have traditionally been grown in wide rows, which enables inter-row cultivation for weed control. Narrow-row production enhances crop–weed competition and increases yield potential (Blackshaw et al. 2000). Before the development of camera-guided machines, inter-row cultivation in narrow-row crops was challenging (Kunz et al. 2015) and limited to manually steered units (Stanley et al. 2018).

Intra-row weeds present a challenge in traditional inter-row cultivation, even when a narrow row spacing is used (Peruzzi et al. 2017). Rotary hoes provide some intra-row control when used at the "white thread" stage of weeds (Vangessel et al. 1995). Post-emergence flex tine-harrowing provides intra-row weed control in cereals without associated crop damage (Rasmussen et al. 2010). Vangessel et al. (1995) observed equivalent weed control when comparing rotary hoeing and tine harrowing in dry beans; however, damage to pinto bean hypocotyls and stems was observed with the tine harrow but not the rotary hoe. The Einböck Aerostar rotary weeder is a new tool that includes tined wheels and resembles a combination of a tine harrow and rotary hoe. Little is known about the tolerance of beans to the rotary weeder at different stages of development. Rotating finger weeders are another tool for intra-row weed control; however, they require very accurate steering to achieve weed control close to the crop rows (Cloutier et al. 2007). Therefore, finger weeders may be well suited to camera-guided systems.

Our objectives were (*i*) to compare the effectiveness of camera-guided inter-row cultivation to the combined camera-guided inter-row cultivation with rotary weeding for weed control in narrow-row dry beans, (*ii*) to evaluate the use of the camera-guided inter-row cultivator when used in tandem with a finger weeder for intra-row weed control in wide-row dry bean production, and (*iii*) to determine the tolerance of narrow-row dry beans to the Einböck rotary weeder at various development stages.

Methods

Field experiments were carried out on a fine sandy loam soil (4.5% organic matter; pH 6.5) at the Ian N. Morrison Research Farm in Carman, Manitoba, Canada in 2018 and 2019. The previous crop in all cases was wheat. Soils were tested for nutrient status and fertilizer N (indigenous soil plus fertilizer = 100 kg N ha^{-1}) and P (30 kg ha^{-1} P_2O_5 to all plots) was broadcast and soil incorporated prior to planting using a cultivator and coil packers during seedbed preparation. The dominant weed species were redroot pigweed (*Amaranthus retroflexus* L.), wild buckwheat (*Fallopia convolvulus* (L.) Á. Löve),

Table 1. Weed biomass, crop biomass, and yield response to weed management treatments in narrow-row pinto bean production in 2018 and 2019 and wide-row production in 2019 in Carman, Manitoba.

Weed control method	Weed biomas (kg ha^{-1})	Crop biomass (kg ha^{-1})	Yield (kg ha^{-1})
Narrow row (15 cm)			
Full herbicide (pre + post)	24.0b	3696.6a	1502.7a
Inter-row cultivation	1953.9a	2798.9b	1112.1b
Rotary weeder	1921.5a	2543.7bc	1012.8b
Rotary weeder, then inter-row cultivation	1495.7a	2927.6b	1059.0b
No control (weedy check)	2460.6a	2076.2c	775.5c
P value	0.0006	<0.0001	0.0102
Wide row (60 cm)			
Full herbicide (pre + post)	46.1d	3284.1a	1918.2a
1× enhanced inter-row cultivation[†]	1006.3bc	2457.1bc	1241.0b
Rotary weeder	1680.2ab	1846.2cd	1095.4b
2× enhanced inter-row cultivation	280.3cd	2855.2ab	1784.6a
No control (weedy check)	2258.1a	1318.5d	588.0c
P value	0.0004	0.0002	0.0001

Note: Within a column, means followed by different letters are significantly different at the 0.05 probability level according to Fisher $LSD_{0.05}$.
[†]Enhanced inter-row cultivation represents addition of finger weeders to inter-row cultivation.

common lambsquarters (*Chenopodium album* L.), and foxtail (*Setaria*) species.

Experiment 1 involved one bean type (pinto bean, cv. Windbreaker) and was conducted under narrow rows (15 cm) in 2018 and both narrow and wide rows (60 cm) in 2019. Seeding was in early June at a target population of 22 plants m^{-2} (narrow row) and 18 plants m^{-2} (wide row). Seed rates were adjusted for germination, emergence, and % cracked seed (seed coat damage). Plots were 5 m wide and 8 m long; an 8 m space between replicates allowed the mechanical weeding equipment to reach operating speed and to allow for the camera/computer to identify the rows. A randomized complete block design with four replicates was used for each experiment.

Treatments in the narrow-row study included the following tillage operations: (1) rotary weeder (2.5 m wide Einböck Aerostar Rotation 300, Einböck GmbH & Co. KG, A-4751 Dorf an der Pram, Austria), (2) inter-row cultivator (4 m wide Robocrop Guided Hoe, Garford Farm Machinery Ltd., Frognall, Peterborough, UK), (3) rotary weeder followed by the inter-row cultivator after 10 days, (4) weedy control, and (5) a herbicide control. The herbicides consisted of a pre-plant incorporated application of granular trifluralin at 848 g a.i. ha^{-1} (Gowan Canada, Winnipeg, Manitoba) applied with a Gandy granular applicator (Gandy Company, Owatonna, MN). In crop application of Viper ADV (imazamox at 20 g a.i. ha^{-1} and bentazon at 429 g a.i. ha^{-1} (BASF, Ludwigshafen, Germany)) and Poast (sethoxydim) was done at 144 g a.i. ha^{-1} (BASF), with an adjuvant (Merge) at 0.5 L ha^{-1} using Teejet Aixr nozzles on a tractor-mounted plot sprayer at a pressure of 275 kPa, a water volume of 9 L ha^{-1}, and a tractor-travel speed of 6 km h^{-1}. Treatments in the wide-row study included: (*i*) rotary weeder, (*ii*) enhanced inter-row cultivator, (*iii*) two passes with enhanced inter-row cultivator 10 days apart, (*iv*) weedy control, and (*v*) full herbicide control. The "enhanced inter-row cultivation" involved both sweeps and rotating finger weeders; the fingers operated from both directions into each bean row, providing delicate weeding within the crop row. Treatments where enhanced inter-row cultivation were used are referred to as either 1× or 2× enhanced cultivation. Mechanical weeding treatments were timed to coincide with the critical period for weed control in dry beans, 3–6 weeks after planting (Burnside et al. 1998).

The machine working depth for the rotary weeder was 2.5–4 cm. Cultivator duckfoot sweeps in the narrow- and wide-row experiments were arranged to operate within 2.5 cm of the plant row and a depth of 4 cm. The combination of sweeps and finger weeders was not possible in narrow rows. Tillage speed was approximately 6 km h^{-1} for all operations.

Crop and weed biomass were sampled separately from three randomly selected 1 m lengths of row within the plots at bean physiological maturity, placed in a drying oven at 60 °C for 48 h and then weighed. The center 10 bean rows were harvested in September with a small plot combine with the exception of 2019 where 4.8 m^{2} of each plot was hand harvested due to extremely wet conditions impeding combine operation. Seed samples were dried on forced air, cleaned, and weighed to determine the final yield. Yield values presented are at air-dried (12%) moisture levels.

A second set of experiments investigated the tolerance of dry beans to the Einböck rotary weeder in narrow-row production (15 cm). Three separate experiments were conducted in 2018; each experiment involved a different bean cultivar (pinto, cv. Windbreaker; navy, cv. T9905; and black bean, cv. Eclipse). A randomized complete block design with four replicates was used for each experiment. In 2019, the experiment included only pinto bean (cv. Windbreaker). In both years, beans were sown on cereal stubble at 22 plants m^{-2}

Table 2. Crop biomass and yield response to rotary weeder applications at different stages of crop growth in pinto bean, black bean, and navy bean production in 2018 in Carman, Manitoba.

Stage	Crop biomass (kg ha $^{-1}$)	Yield (kg ha $^{-1}$)
Pinto bean		
Ground crack/hook	5379.2	1408.4a
VC	4298.2	1267.6ab
V1–V2	4443.0	1232.9ab
V3–V5	4763.8	1311ab
V8	3509.3	1115.2b
R1	4143.2	715.1c
Weed-free	4471.8	1262.2ab
P value	NS	0.0011
Black bean		
Ground crack/hook	4670.7	1394.7
VC	4419.3	1197.3
V1	5014.4	1381.8
V2–V3	4291.2	1374.5
V5	4527.1	1223
R1	4343.7	1162.7
Weed-free	4694.4	1254.8
P value	NS	NS
Navy bean		
VE–VC	5708.3	1454.0ab
VC–V1	6490.3	1578.9a
V2–V3	6824.3	1439.5ab
V4–V5	5468.5	1141.2c
R1	5654.4	1299.0bc
Weed-free	5825.5	1372.27b
P value	NS	0.0069

Note: Within a column, means followed by different letters are significantly different at the 0.05 probability level according to Fisher $LSD_{0.05}$.

in 4 m × 8 m plots. Similar to methods in experiment 1, all plots were fertilized based on soil test recommendations and maintained weed-free through herbicide application, and hand weeding if required. Treatments included rotary weeding at weekly intervals beginning at the crook stage, with the final timing at the R1 stage.

The data were analysed using the PROC Mixed procedure in SAS 9.4 (SAS Institute 2013). Treatments, site-years, and site-year × treatment were considered fixed effects and replicates nested within site-years were considered random effects. In the case of the 2019 wide-row study, only replicate was considered in the random statement, as there is only one site-year of data. The PROC Univariate procedure was used to test for the normality of residuals. If homogeneity of the residuals was not met upon visual inspection of the residual panel of the predicted values vs. the residual values, a repeated/group statement (group = treatment, group = site-year, group = site-year × treatment) was used to account for the heterogeneity of variance. Following the visual inspection, the best fit was identified by using the lowest Akaike information criterion values. The variables analysed included yield at air-dried moisture, crop biomass, and weed biomass.

Results and discussion

No site-year × weed control interactions were observed for narrow-row production; therefore, a combined site-year analysis was conducted. Results showed that inter-row cultivation in narrow-row production significantly increased crop biomass over the weedy check (Table 1). No significant differences in weed biomass were observed between the inter-row cultivation and the weedy control. The combination of the rotary weeder and inter-row cultivation alone produced similar ($P > 0.05$) crop biomass to inter-row cultivation alone, indicating no advantage to adding rotary weeding 10 days prior to inter-row cultivation. Also, rotary weeding did not show any advantage in crop biomass compared with the weedy control. For seed yield, all mechanical treatments resulted in significantly greater yield than the weedy control (23%–30% increase), but were significantly lower than the full herbicide treatment. Improved bean yield with mechanical weeding was attributed to lower (though not significant) weed biomass (Table 1).

Results of the wide-row study showed that inter-row cultivation reduced weed biomass significantly compared with the weedy control (Table 1). The 2× enhanced inter-row cultivation resulted in a similar level of weed biomass to the herbicide control treatment. The 2× enhanced inter-row cultivation treatment also resulted in crop biomass and yield levels similar ($P > 0.05$) to the herbicide control (Table 1), demonstrating the potential of mechanical weed control. The 1× enhanced inter-row cultivation resulted in similar crop biomass to the 2x treatment, but lower dry bean yield. Therefore, two passes with the cultivator were better than one.

It is not clear how much the finger weeders contributed to the superior weed control in the enhanced inter-row cultivation in this experiment. Future research should investigate the camera-guided system with and without finger weeders. Field observations showed significant intra-row weed control with the finger weeders, which were able to operate effectively due to the precision of the camera guidance system.

The rotary weeder was used in experiment 1 in an attempt to directly remove intra-row weeds. While results showed some benefit of the rotary weeder for suppression of weed biomass (Table 1), the impact was not statistically significant. This raised the question of crop tolerance to the mechanical action of the rotary weeder. Was the lack of yield enhancement caused by mechanical damage to the bean crop? Therefore, a second set of experiments were conducted to investigate the tolerance of dry beans to the rotary weeder at different stages of development. Results showed that beans were generally tolerant of the rotary weeding treatment. For example, crop biomass and seed yield were unaffected by rotary weeding between VE and V3 in all three bean types: navy, pinto, and black bean (Table 2). There were several instances where rotary weeding later in the season (V5–R1) resulted in less crop yield, though results were not consistent among bean types (Table 2). However, the lack of difference in crop production between the rotary treatments and the weed-free/no rotary treatment between VE and V3 demonstrates that dry beans appear to be quite tolerant of this tool during the critical weed-free period.

Future research is required to understand the effects of these mechanical tools under a wider range of conditions. For example, visual observation from experiment 1 showed that the rotary weeder resulted in established weeds uniformly across the plots (within and between rows), whereas inter-row cultivation alone resulted in weeds concentrated in the crop row. Robotic weeders that target the area between plants within a row are available for spaced plants (eg., sugar beet). However, these may not be appropriate for dry beans that have a greater in-row density (Melander and McCollough 2021), so future use of finger weeders with camera guidance may be more practical. This study was conducted with broadleaved weeds and small-seeded *Setaria* species. Studies are required to test these systems in the presence of harder to control weeds such as wild oats (*Avena fatua*) or perennial species.

Conclusion

The mechanical treatments resulted in significantly less weed biomass (wide row only) and significantly more crop biomass (both narrow- and wide-row production) compared with the weedy control. Dry bean yield was increased over the weedy control with mechanical treatments in all cases, though yields were similar to the full herbicide treatment only for the 2x enhanced cultivation in wide-row production. That one-time study demonstrated the potential of adding finger weeders to camera-guided inter-row cultivation in wide-row bean production. A companion study demonstrated high tolerance of dry beans to the Einböck rotary weeder.

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Data availability

Data are available from the corresponding author upon reasonable request.

Author information

Author ORCIDs

M.H. Entz https://orcid.org/0000-0002-2319-4499

Author contributions

KAS: conceptualization, conducted field experiment, data analysis, and final draft.
MHE: conceptualization, funding acquisition, and final draft.

Competing interests

There are no competing interests.

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