Performance of Different Roller Designs in Terminating Rye Cover Crop and Reducing Vibration

T. S. Kornecki, A. J. Price, R. L. Raper

Abstract. *Rollers may provide a viable alternative to herbicides for terminating cover crops; however, excessive vibration generated by rollers and transferred to tractors hinders the adoption of this technology in the United States. To avoid excessive vibration, producers must limit their operational speed, which increases time and cost of rolling. The effect of speed on cover crop termination rate and vibration level was tested on several roller designs. Two field experiments were conducted with different roller designs to terminate a cover crop of rye (*Secale cereale *L.). In the first experiment, three single-section roller designs (long straight bars, curved blunt bars, and a smooth roller with an oscillating crimping bar) were tested at 1.6, 4.8, and 8 km/h operating speeds. In the second experiment, two triple-section commercial width rollers, one with long straight bars and the other, a smooth roller with an oscillating crimping bar, were tested at speeds 3.2 and 6.4 km/h. Data from the first experiment showed that all three roller designs terminated at levels greater than 90% with the highest termination rate produced by the smooth roller with crimping bar (93.4%). Three weeks after rolling, termination rates varied from 88.3% to 94.0% for all designs and speed ranges, all of which were sufficient mortality rates for rye before planting a cash crop without need to use herbicide. Reduced vibration levels measured on the tractor's frame were generated by the smooth roller with oscillating crimping bar with the highest vibration levels being generated by the roller with the straight bars. In the second experiment, three weeks after rolling significantly higher rye termination rates resulted from the roller with long straight bars (96%) in comparison with the smooth roller (94%). Despite these differences, both rollers effectively terminated rye prior to planting without use of herbicides. The smooth roller with crimping bar transferred significantly lower vibration levels to the tractor's frame than long straight bar roller at both speeds but vibration levels exceeded acceptable health and comfort levels.*

Keywords. *Roller/crimper testing, Vibration, Cover crop mortality, Conservation tillage.*

A report by Conservation Technology Information Center (CTIC) (2003) showed that between 1990 and 2002 the number of Southern U.S. cropland area planted in conservation systems without surface tillage increased from 5.7 to 7.0 million ha (14.0 to 17.2 million acres). This significant increase can be attributed to positive benefits of winter cover crops as an integral component of conservation tillage systems. Cover crops are a vital part of conservation tillage systems, but they have to be managed appropriately to get their full benefits (Brady and Weil, 1999). These benefits include weed pressure reduction caused by alleopathy and improving soil properties due to mulch effects and increased soil organic matter. Several studies identified other benefits, such as increased water infiltration, reduced runoff, reduced soil erosion, and reduced detrimental effects of soil compaction (McGregor and Mutchler, 1992; Kern and Johnson, 1993; Reeves, 1994; Raper et al., 2000a, 2000b).

Rye is commonly used as a winter cover crop in the Southern United States. Timely termination of cover crops before planting provides maximum benefits to cash crops, such as cotton. Most agricultural extension services recommend terminating the cover crop at least two weeks prior to planting the cash crop to prevent the cover crop from using valuable spring moisture that could be used by the main cash crop after planting. Hargrove and Frye (1987) stated that a termination date at least 14 days before planting of cash crop enabled soil water recharge by the planting time. In conservation systems, terminating cover crops three weeks prior to planting the cash crop is a standard recommendation (Ashford and Reeves, 2003).

Terminating cover crops has been mainly accomplished by the use of herbicides, since spraying is relatively fast and effective. However, for a cover crop (rye) that is very tall and lodges in multiple directions, planting efficiency can be reduced due to a need for frequent stops to clean accumulated cover crop residue from planting units. In addition, non-rolled residue may cause hair-pinning, a condition where lodged residue prevents adequate seed-soil contact.

Flattening and crimping cover crops by mechanical rollers is widely used in South America, especially in Brazil, to successfully terminate cover crops without herbicides (Derpsch et al., 1991). Original roller design consisted of a round drum with equally spaced blunt straight steel bars around the drum's perimeter and across the drum's length. The function of the bars is to crimp or crush the cover crop

Submitted for review in December 2004 as manuscript number PM 5667; approved for publication by the Power & Machinery Division of ASABE in June 2006.

The use of trade names or company names does not imply endorsement by USDA-ARS.

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stems without cutting them, otherwise the cover crops can re-sprout and loose residue may interfere with planting operations. Because of potential environmental and monetary benefits (no use of herbicides), this technology is now receiving increased interest in North America. Ashford and Reeves (2003) investigated benefits of rolling cover crops in Southeastern United States by comparing a cover crop termination rate during a 28-day period using a roller alone and a roller with different herbicides and application rates. They indicated that when rolling was conducted at the appropriate plant growth stage (i.e. soft dough), the roller was equally effective (as chemical herbicides) at terminating the cover crop (94%). According to Ashford and Reeves (2003), no significant differences in kill rate were found between chemical and mechanical termination by the roller between 14 and 28 days prior to planting, and rye mortality above 90% was sufficient to begin planting of cash crop due to accelerated cover crop senescence. Another important aspect of rolling cover crops is that a flat mat is created that lies in the direction of travel. This allows farmers to use planters for cash crop operating in parallel to the rolled cover crop direction, which has been successful in obtaining proper plant establishment. Using smooth rollers without crimping alone to flatten the cover crop and prevent multiple-direction lodging is also beneficial in terms of minimizing interactions between the residue and the planter.

In the United States rollers/crimpers (based on the original design) have been used in some conservation systems to manage cover crops, but North American producers reported problems with these implements. The main complaint has been the excessive vibration generated by the rollers with straight crimping bars around the drum's perimeter (personal communications with R. L. Raper and D. W. Reeves, 2004). According to Raper et al. (2004), high vibrations and low operating speeds associated with current roller designs adopted from Brazil resulted in a low rate of adoption by farmers.

Research shows that vibrations generated by mobile equipment (trucks, tractors, earth and agricultural machinery) have negative effects on human health. Common symptoms from exposure to vibration are increased heart rate, headache, stomach pain, lower back pain, and spinal degeneration in cases when human exposure to vibration continued for years (Bovenzi, 1996; Toren et al., 2002; Muzammil et al., 2004). Vibration is usually reported as an acceleration based on an accepted convention (Thomson, 1988) and in accordance with the format for vibration limits that are harmful to the human body developed by International Standard Office (ISO, 1997). Vibration levels from 1.25 to 2.0 m/s^2 are classified as "very uncomfortable" and vibrations above 2.0 m/s^2 are considered "extremely uncomfortable" (ISO, 1997). Australian Standards developed limits for 8-h human exposure to vibrations; for comfort limit, fatigue limit, and health limit (detrimental effect) vibrations levels should be 0.1, 0.315, and 0.63 m/s^2, respectively (Mabbott, 2001).

The most effective method of alleviating the vibration has been to reduce travel speed, but this is not desirable or economical. Most producers find this to be an unacceptable solution due to the much higher operating speeds that they were able to previously use for spraying herbicides onto cover crops. To determine the effect of different speeds on roller's effectiveness (termination rate) and vibration, two separate experiments were conducted. Experiment 1 evaluated three single-section designs (1.8 m wide). Experiment 2 evaluated two triple-section roller designs (4.1-m commercial width) as typical farming operations.

The objectives of this study were:

- determine the effectiveness of different roller designs in terminating cover crop,
- determine the operating speed effect on termination rate for different roller types,
- determine vibration levels generated by different roller designs at different operating speeds.

Materials and Methods

Experiments were conducted at the Alabama Agricultural Experiment Station's E.V. Smith Research Station near Shorter, Alabama, on a Compass loamy sand soil (thermic Plinthic Paleudults). Rye was planted in fall 2003. The experiments were conducted in mid-April 2004 when the cover crop was in the soft dough growth stage (Nelson et al., 1995), which is a desirable growth stage for termination. Rye mortality, based on visual desiccation, was estimated on a scale of 0 (no injury symptoms) to 100 (complete death of all plants) a method commonly used in weed science (Frans et al. 1986), and was evaluated on a weekly basis at one, two, and three weeks after rolling treatments.

Experiment 1

Three different roller designs of a 1.8-m single-section width were used to determine the performance of each roller design in terms of termination rate and amount of vibration while operating at various operating speeds. Rolling direction, that is always parallel to a future cash crop planting direction, was perpendicular to rye rows to generate the most uneven field surface conditions and to account for broadcasting of rye instead using a drill. The experiment was a completely randomized block design with four replications comparing three roller-crimper designs at three tractor speeds. Total of 36 plots were used. Each plot was 15 m long and 1.8 m wide. Before rolling the cover crop, the height of rye was measured (randomly selected 10 counts per plot). In addition, biomass samples were collected (0.5-m^2 sample area) and dried at 60°C to estimate the amount of dry mass produced in each plot. Three treatments of different roller designs were used: (1) long-straight bars (fig. 1a), (2) curved bars (fig. 1b), and (3) smooth roller with an oscillating crimping bar (patent pending) (fig. 1c).

The operating speeds were 1.6, 4.8, and 8 km/h to explain speed effects on kill rates and vibration representing the minimum and maximum speed range commonly used in rolling operations. Accelerometers from Crossbow Technology Inc. (San Jose, Calif.) were mounted on the tractor's frame to measure vertical vibration levels to which driver was subjected (fig. 2a) and on the roller's frame to measure roller vertical vibration (fig. 2b). Vibration data from accelerometers was recorded to a computer by a custom made "on board" data acquisition system and special software and data were analyzed using peak acceleration values.

Figure 1. Roller types: (a) roller with attached long-straight crimping bars, (b) roller with curved crimping bars, (c) smooth roller with an oscillating crimping bar.

Experiment 2

Two different roller designs of 4.1-m commercial width were used at two operating speeds to investigate the effectiveness in terminating rye and to determine vibration levels generated by the rollers, (1) long-straight bars and (2) smooth roller with an oscillating crimping bar.

The first roller was a three-piece assembly (fig. 3a) constructed by Bigham Brothers, Inc. (Lubbock, Tex.). The second roller was a three-piece assembly prototype of the smooth roller with an oscillating crimping bar (patent pending) developed and fabricated at the USDA-ARS-NSDL (fig. 3b). The curved roller was not included in this experiment because no commercial unit was available at the time of the rolling experiment in spring 2004. A completely randomized block design was used with four replications. A total of 16 plots were used with each plot measuring 15 m long and 4.1 m wide. Before rolling (similarly to the first experiment) the height and the biomass of rye were measured. The operating speeds were 3.2 and 6.4 km/h. As in the first experiment, Crossbow accelerometers were mounted on the tractor's frame to measure vibration levels (recorded by "on board" data acquisition system) and on the roller's frame to measure vibration due to the roller's motion. Rolling direction was parallel both to rye rows and intended cash crop planting direction.

For both experiments, the percentage of rye mortality data were transformed using an arcsine square-root transformation method (Steel and Torrie, 1980), but this transformation did not result in a change in the analysis of variance. Thus, non-transformed means are presented. For vibration analysis original vibration data were used. Treatment means were separated by the Fisher's protected least significant difference test at the 0.10 probability level. Data were separately analyzed after the second and the third weeks using SAS (Statistical Analysis Software) ANOVA Analyst's linear model.

Results and Discussion

Experiment 1 (Single-Section Rollers: 1.8 m Wide)

Speed Effect

The average height of rye was 1.2 m with the average dry mass of 650-g/m^2 unit area. No mortality rates for rye were reported after the first week from rolling because these rates were only slightly above 20% for all three roller types. After the second week from rolling, no significant differences in rye mortality were found between three operating speeds for each roller type (table 1). However, with an increase in operating speed of straight bar roller there was a slight

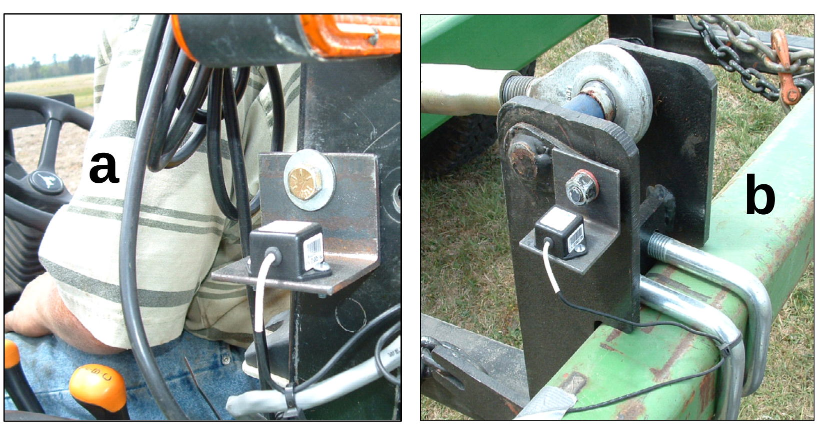

Figure 2. Placement of one-dimensional (z-axis) accelerometer to measure vertical acceleration from Crossbow Technology Inc.: (a) tractor's frame and (b) roller's frame.

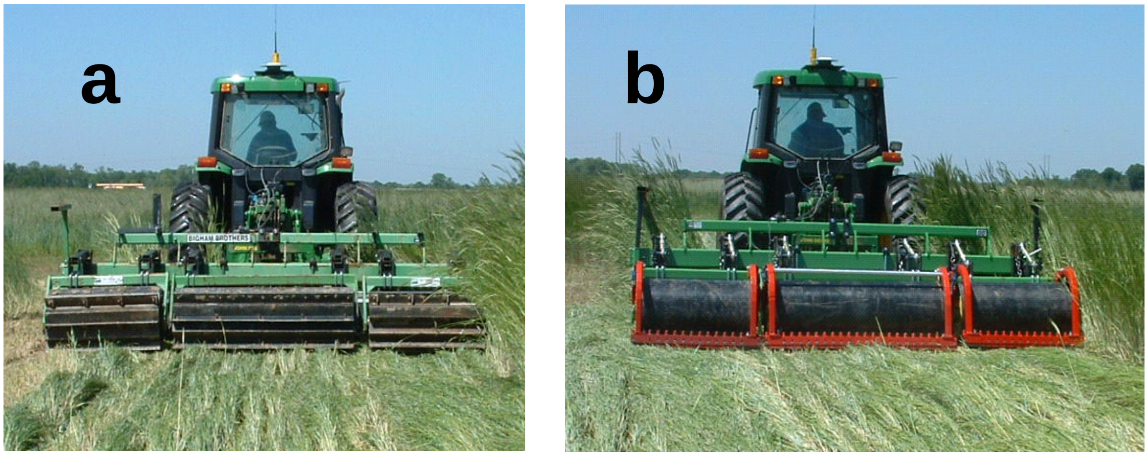

Figure 3. Commercial roller types: (a) roller with long straight bars and (b) smooth roller with oscillating crimping bars.

Table 1. Speed effect on rye termination rate (%) for different weeks after rolling/crimping and roller types.

		Roller Type		
Time after Rolling	Speed (km/h)	Straight w/ Crimping Bars	Curved w/ Crimping Bars	Smooth w/ Oscillating Crimping Bar
Week 2	1.6	38.8a	38.8a	43.8a
	4.8	41.3a	38.8a	45.0a
	8.0	42.5a	38.a	45.0a
	LSD (0.1)	6.6	4.6	5.9
Week 3	1.6	88.3a	90.0a	94.0a
	4.8	93.3a	90.0a	92.5a
	8.0	90.5a	90.0a	93.8a
	LSD (0.1)	6.5	3.2	2.4

[a] Means of rye mortality (%) within columns among roller types for three speeds with the same letters are not significantly different at the 10% level. Mean comparisons are separate for the second and the third week.

increase in mortality rate, suggesting that an increase of the roller's speed might generate higher crimping forces. The straight bar roller only contacts the cover crop at certain discriminate points, i.e. the crimping bars, suggesting that higher crimping forces result from the vibratory motion of the straight bar roller. After the third week from rolling, increased operating speed did not affect mortality rates for each roller type. This lack of a speed effect might be related to the natural and accelerated plant senescence and to initial plant injury due to crimping as reported by Ashford and Reeves (2003).

Roller Type Effect

To compare the effectiveness of each roller type, their termination rates were averaged over all speeds for the second and third week after rolling. These data showed there were significant differences in termination rates between roller types (fig. 4). After the second and the third week from rolling, the smooth roller with crimping bar produced a significantly higher mortality rate in comparison with other type rollers. The lowest mortality rate of 90% was generated by the roller with curved bars and might be associated with the continuous contact of crimping bars and cover crop during rolling operation rather than through single contacts of crimping bars attached to straight bar roller. After the third week of rolling, the rye mortality were 93.4%, 90.7%, and 90.0% for smooth roller with an oscillating crimping bar, roller with straight crimping bars, and roller with curved bars, respectively (fig. 4). Based on recommendations from

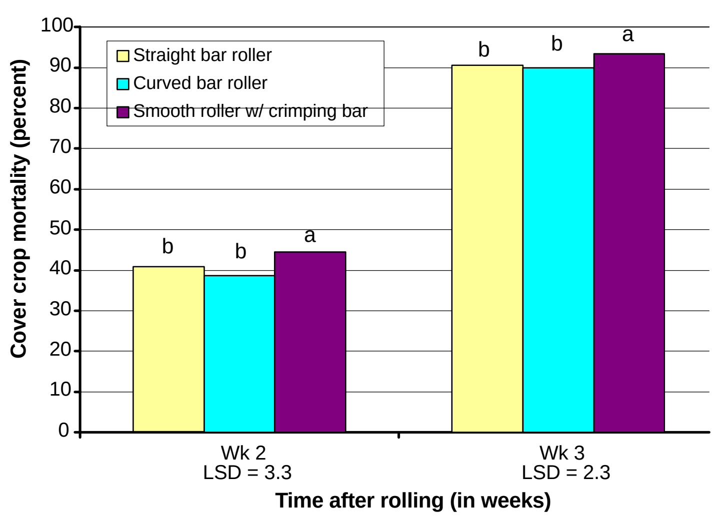

Figure 4. Cumulative rye mortality comparison between roller types averaged over speeds after two and three weeks from rolling. Means with the same letters are not significantly different at the 10% level.

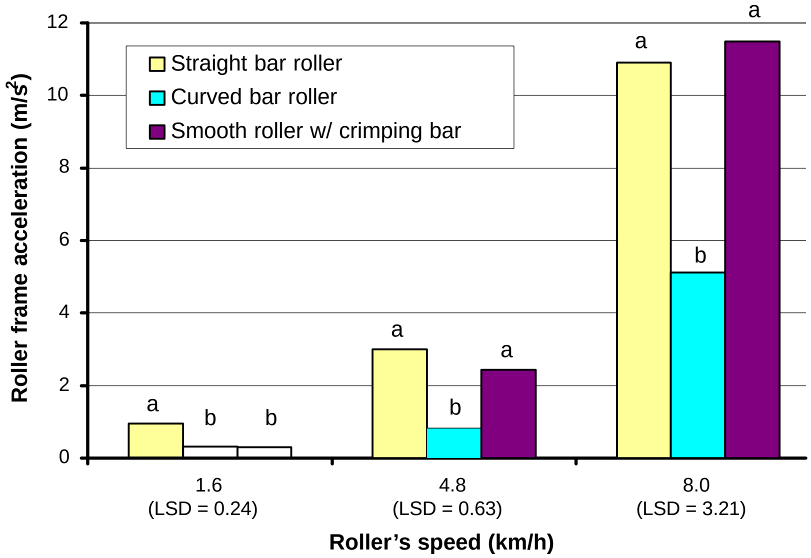

Figure 5. Vibration levels measured at the roller frame among three roller types at each operating speed. Means with the same letters are not significantly different at the 10% level.

Ashford and Reeves (2003), rye mortality rates generated by any of the three roller types were high enough (90% and above) to begin planting of a cash crop.

Roller Frame Vibration Level

To determine if the roller type had an effect on vibration level measured on roller frame, vibrations generated by each roller under different speeds were compared (fig. 5). At 1.6 km/h, a significantly higher vibration level was generated by the roller with straight crimping bars. At 4.8 and 8.0 km/h, significantly higher vibration levels were generated by the roller with straight bars and the smooth roller with an oscillating bar in comparison with the curved bars roller. However, at 4.8 and 8.0 km/h, no significant differences were found between vibration levels generated on roller's frame by the roller with straight bars and smooth roller with crimping bar (fig. 5).

Speed effects on vibration level generated by each roller were also examined (fig. 6). With increasing operating speed, vibration levels increased with each roller type. No significant differences in vibration levels generated by the rollers with straight bars and curved bars were found at 1.6 and 4.8 km/h. However, significantly higher vibration levels were found at 8.0 km/h for all the roller types. With increasing operating speed, the smooth roller with an oscillating crimping bar generated significantly higher vibration levels due to higher velocity of the oscillating crimping bar (fig. 6).

Tractor Frame Vibration Level

Vibration levels generated by rollers that are transferred to tractor frame and operator are important in terms of having possible negative effects on human health. Although vibration increased with increasing speed, especially at 8.0 km/h, no significant differences in vibration levels transferred to the tractor frame were found for all three roller types at each operating speed (fig. 7). At a speed of 8.0 km/h, the highest vibration level was recorded at for the roller with straight bars, and the lowest vibration level was found with smooth roller with oscillating crimping bar. Lower vibration levels transferred by the smooth roller to the tractor's frame might be contributed by the right geometry of the crimping bar and

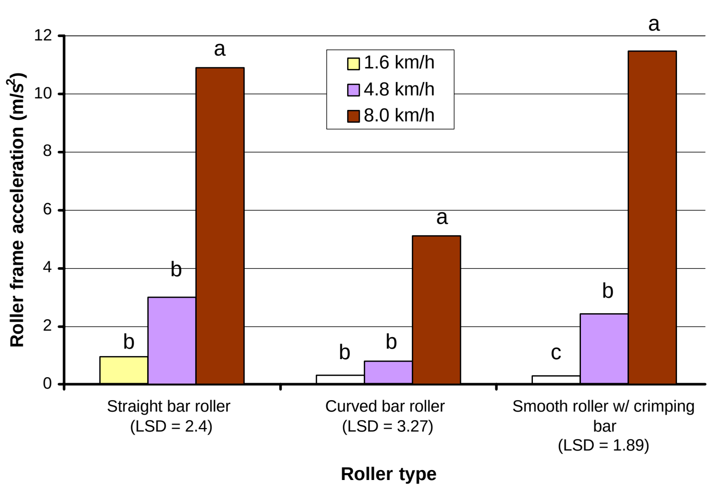

Figure 6. Vibration levels measured at roller's frame at different speeds. Means with the same letters for each roller type are not significantly different at the 10% level.

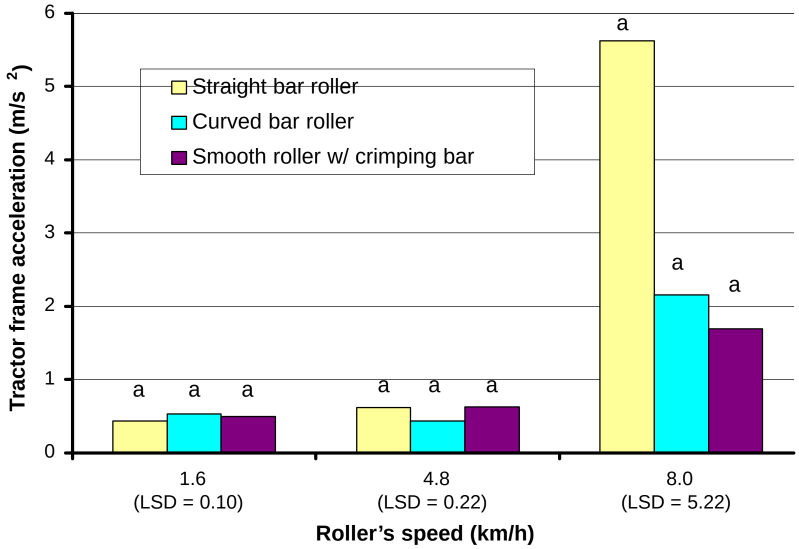

Figure 7. Vibration levels measured at the tractor's frame among three roller types at different speeds. Means with the same letters at each speed are not significantly different at the 10% level.

the specific location of two pivot points mounted on ther oller's frame, which allows for proper engagement of thec rimping bar with the rye cover. It appears that the energy from the oscillating crimping bar was effectively transferred to a flat, rolled mat of the cover crop; thus lowering vibration transferred to the tractor (fig. 7).

Significantly higher vibration levels were found at 8 km/h for the roller with curved bars and the smooth roller with oscillating crimping bar when compared to vibration levels at lower speeds (fig. 8). For the roller with straight bars, no significant differences were found between operating speeds, although with the increase in operating speed, vibration levels also increased. Lack of significant differences in vibration levels generated by the roller with straight bars between operating speeds might be associated with greater variability in vibrations caused by the abrupt acceleration of the roller's mass between each crimp due to forward motion on the uneven soil surface. The roller with straight crimping bars makes contact with the soil surface only through a single bar at a time rather than by continuous contact. Such motion might contribute to rapid changes in the tractor's frequency resulting in increased vibration levels.

According to International Standard Office (ISO, 1997), vibration transferred to the tractor frame and operator at 8.0 km/h by the straight long bar roller (5.6 m/s^2) exceeded very uncomfortable (1.25 to 2.0 m/s^2) and extremely uncomfortable limits (above 2.0 m/s^2). Australian Standards developed for 8-h human exposure to vibrations recommended that for comfort limit, fatigue limit, and health limit (detrimental effect) vibrations levels should be 0.1, 0.315, and 0.63 m/s^2, respectively (Mabbott, 2001). Vibration levels generated by the three rollers, especially at 8.0 km/h exceeded ISO and Australian limits, however, the smooth roller with crimping bar at 8.0 km/h generated less vibration levels on the tractor frame (1.8 m/s^2) that was below the "extremely uncomfortable limit" as determined by ISO (1997). Roller with curved bars slightly exceeded that limit generating 2.1 m/s^2 at 8.0 km/h.

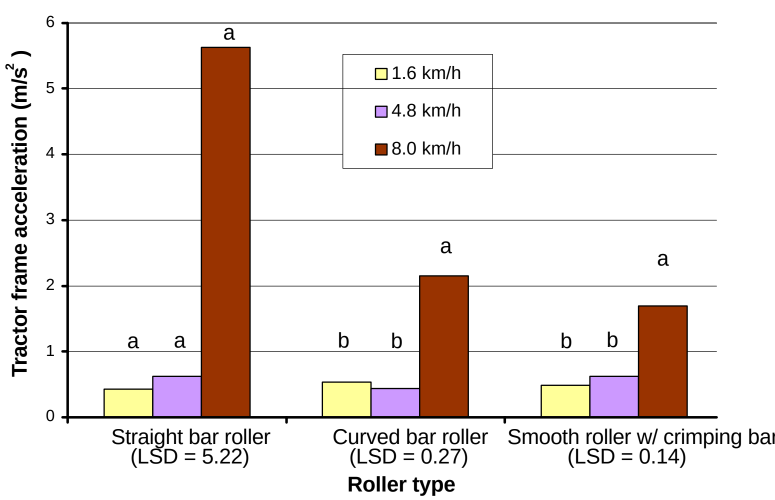

Figure 8. Vibration level measured at the tractor's frame for each roller type averaged over all speeds. Means with the same letters are not significantly different at the 10% level.

Table 3. Speed effects on rye mortality (%) for three-sections roller type and different weeks after rolling/crimping.[a]

Time after Rolling	Straight Bar Roller (3.2 km/h)	Smooth Roller w/Crimping Bars (3.2 km/h)	Straight Bar Roller (6.4 km/h)	Smooth Roller w/Crimping Bars (6.4 km/h)	LSD (0.1)
	Roller Type and Speed (treatment)				
Week 2	32.5a	26.3b	32.5a	30.0ab	3.8
Week 3	96.0a	94.5b	96.5a	94.0b	1.3

[a] Values of the means within rows with the same letters are not significantly different at the 10% level.

Experiment 2 (Triple-Section Rollers: 4.1 m Wide)

Roller Type and Speed

The average height of rye was 1.7 m with an average dry mass of 625-g/m^2 unit area. Two weeks after rolling, significantly higher rye mortality were found with the straight bar roller at both speeds in comparison with the smooth roller with crimping bar at 3.2 km/h (table 3). Increase in operating speed did not affect mortality rates for both rollers. Three weeks after rolling significantly higher kill rate for rye was recorded for roller with long straight bars at both speeds in comparison with the smooth roller with crimping bar (table 3). Despite these differences both rollers effectively terminated the cover crop (> 94%) without the need for chemical application, which correspond to cover crop mortality rate threshold above the 90% necessary to plant a cash crop as reported by Ashford and Reeves (2003).

When comparing results for both rollers in the second experiment, in contrast to the first experiment, smooth roller with crimping bar produced significantly lower rye mortality than the straight long bar roller. This difference might be explained by incomplete contact of oscillating bar with the ground. This insufficient contact was caused by depressions created by tractor tires in the soft soil, which reduced contact of crimping bar against the rolled cover crop. Higher termination rates produced by long straight bars were most likely due to the higher pressure from long crimping bars which resulted in deeper bar penetrations into the rye, thus nearly eliminating empty pockets between tire depressions and crimping surfaces of crimping bars.

Vibrations

The commercial-size roller (4.1-m wide) weighed at least three times more than the experimental single-section rollers (1400 kg). Triple-section rollers generated higher vibration levels than single-section rollers, thus, the resulting forces would likely be much higher in magnitude (due to increased weight) and could cause possible machine failure and increased discomfort to the operator.

Vibration levels generated by the two rollers, measured on roller's frame, were not significantly different at the same operating speed (fig. 9). At 3.2 km/h, the roller with straight crimping bars generated 6.47 m/s^2, whereas the smooth roller with the oscillating crimping bar generated 4.66 m/s^2. With increased operating speed to 6.4 km/h, vibration levels significantly increased for both rollers to 14.4 m/s^2 for straight bar and for smooth roller with the oscillating bar to 15.86 m/s^2 (fig. 9).

The smooth roller transferred significantly lower vibration levels to the tractor's frame at both speeds in comparison with long straight bars roller (fig. 10). It appears that the roller with crimping bar transferred some of its energy to the cover crop, thus lowering vibration transferred to the tractor. Tractor frame vibration levels at both operating speeds were not significant for each roller type. However, there were significant differences between roller types at both speeds (fig. 10). Similarly, as in the first experiment, vibration levels generated by the two rollers on the tractor frame were above ISO (1997) and Australian limits (Mabbott et al., 2001). However, the smooth roller with crimping bar generated significantly lower vibration levels: 0.5 and 0.88 m/s^2 at 3.2

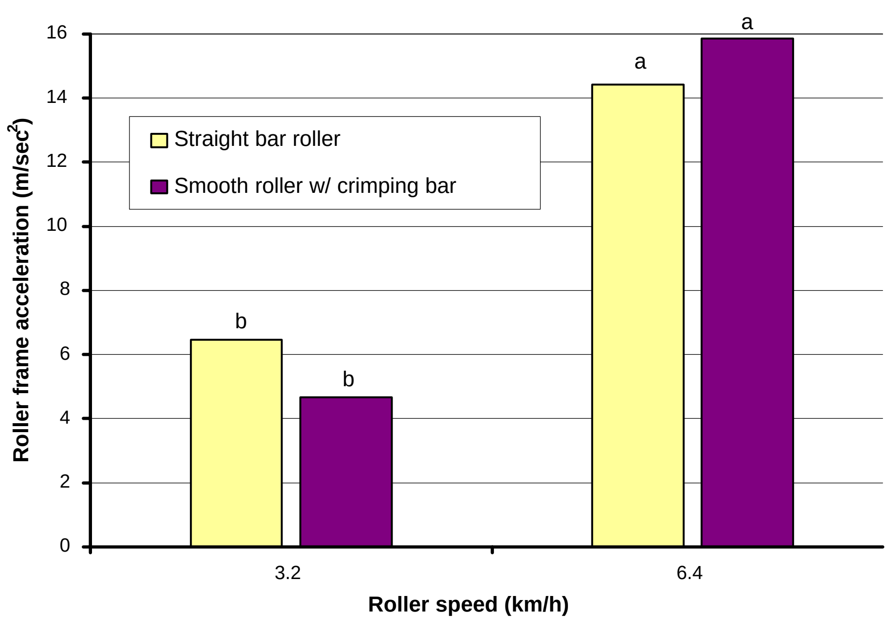

Figure 9. Vibration levels measured on roller's frame. Means with the same letters for speeds and roller types are not significantly different at the 10% level (LSD = 3.21 m/s^2).

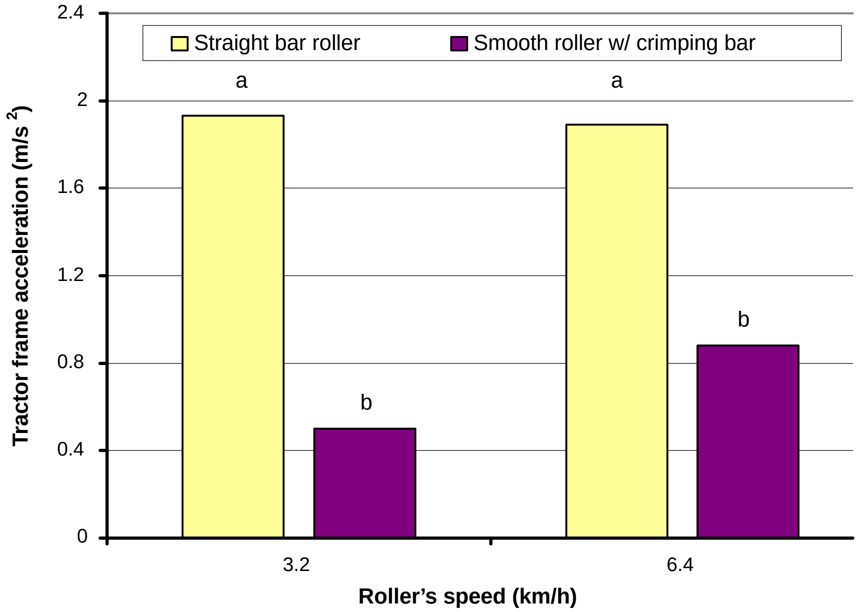

Figure 10. Vibration levels measured on tractor's frame. Means with the same letters for speeds and roller types are not significantly different at the 10% level (LSD = 0.6 m/s^2).

and 6.4 km/h, respectively, that are below the "very uncomfortable limit" as determined by ISO (1997). On the other hand, straight bar roller generated vibration levels of 1.93 and 1.89 m/s^2 at 3.2 and 6.4 km/h, respectively, that was within a "very uncomfortable limit" and could cause a discomfort to the operator.

Conclusions

- An increase in operating speed did not have significant effects on rye mortality after the second and the third week from rolling for all roller types (single-section rollers).
- After the second and the third week from rolling significantly higher rye mortality were found with the smooth roller with crimping bar (single-section rollers). However, after three weeks of rolling all single-section roller types produced above 90% rye mortality that is recommended for planting a cash crop without using herbicides.
- At the higher operating speed of 8 km/h, lower acceleration levels measured on the tractor's frame were generated by the smooth roller with oscillating crimping bar and by the roller with curved bars. The roller with straight long bars generated the twice higher acceleration levels on the tractor's frame in comparison with curved bars and smooth-crimping bar rollers (single-section rollers).
- Both triple-section roller types effectively terminated cover crop (> 94%) three weeks after rolling, without the need of herbicide.
- Increase in operating speed increased acceleration levels, measured on the roller's frame for both (triple-section) roller types. However, no differences in vibration levels on the roller's frame were found between the two types of rollers generated at the same operating speed.
- At both speeds, the smooth roller with crimping bar generated lower vibration levels on the tractor's frame than the straight bar roller. These vibration levels were below "very uncomfortable limit" as determined by ISO (1997), but still exceeded the Australian 8-h limits for comfort and fatigue at both speeds and health limits at 6.4 km/h. Further research is needed to study the tractor's and roller's vibration frequencies to improve roller design and to further reducing tractor frame vibrations at higher operating speeds than used for this study.

Acknowledgements

The authors wish to thank Mr. Eric Schwab, Mr. Dexter LaGrand, Mr. John Walden, and Mr. Morris Welch for their invaluable assistance in roller construction, conducting field experiments, instrumentation, and data collection.

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