Evaluation of a prototype sea buckthorn leaf harvester

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Mann, D.D., Petkau, D.S., and Crowe, T.G. 2003. **Evaluation of a prototype sea buckthorn leaf harvester.** Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **45**: 2.9-2.15. Sea buckthorn (*Hippophae rhamnoides* L.) is a thorny shrub with yellow-orange berries and silver-gray leaves that both contain compounds with nutritional and pharmaceutical qualities. Recent interest in the establishment of a sea buckthorn industry in North America has identified the need for mechanical harvesting equipment for both sea buckthorn berries and leaves. A brush-type leaf harvester has been designed and tested. With a small, hand-held prototype, the best harvest rate observed was 10.5 g/s using 1.5-mm diameter nylon bristles rotating at 525 rpm. With a larger, trailer-mounted prototype, a harvest rate of 17.0 g/s was observed using 1.0-mm diameter polypropylene bristles rotating at 500 rpm. The effectiveness of a brush-type harvester was found to depend on the aggressiveness of the brush head. The mass of both leaves and small branches removed increased as the bristle diameter and brush rotational speed increased. Nylon bristles of 1.5-mm diameter removed almost as much debris as leaves (measured on a mass basis) and, consequently, were deemed to be too aggressive. Polypropylene bristles of 1.0-mm diameter operated at either 350 or 500 rpm removed a substantial mass of leaves without removing too many branches. Based on preliminary assessment of the damage caused by the trailer-mounted harvester, 87% of the shrubs were considered to be in "good" condition, although 38% of the shrubs had localized regions of severe bark damage. During a subsequent damage assessment at the beginning of the next growing season, only 40% of the shrubs were considered to be in "good" condition. The severe bark damage was still visible. Overall, 72% of the leaves removed from the shrubs were captured by the collection system.
Keywords: *Hippophae rhamnoides* L., leaf collector, damage assessment.

L'argousier (*Hippophae rhamnoides* L.) est un arbuste épineux qui produit des baies jaunes oranges et des feuilles gris argenté qui tous les deux contiennent des composés possédant des propriétés nutritionnelles et pharmaceutiques. L'intérêt récent pour la production de l'argousier en Amérique du Nord explique le besoin de développer un équipement de récolte mécanique pour les baies et les feuilles. Une récolteuse à brosses pour les feuilles a été développée et testée. À l'aide d'un prototype à main utilisant des brosses munies de soies en nylon ayant un diamètre de 1,5 mm et tournant à une vitesse de 525 tpm, le meilleur taux de récolte obtenu a atteint 10,5 g/s. Une deuxième machine de type semi-remorquée munie de brosses en polypropylène ayant des s oies de 1,0 mm de diamètre et opérées à une vitesse de 500 tpm a permis d'atteindre un taux de récolte de 17,0 g/s. Ces essais ont démontré que l'efficacité de ce type de récolteuse à brosses dépend de l'aggressivité des brosses elles-mêmes. En effet, la masse de feuilles et de petites branches prélevée des arbustes a augmenté avec un accroissement du diamètre des soies des brosses ainsi que de leur vitesse de rotation. Les soies en nylon d'un diamètre de 1,5 mm ont été jugées trop agressives parce qu'elles ont prélevé autant de débris que de feuilles sur une base massique. De leur côté, les brosses dotées de soies en polypropylène d'un diamètre de 1,0 mm et opérées à une vitesse angulaire de 350 ou 500 tpm ont permis le prélèvemen t d'une masse substantielle de feuilles exemptes de branches. Une estimation préliminaire des dommages causés aux arbustes par le prototype semi-remorqué a permis d'établir que 87% de ceux-ci étaient en "bonne" condition tandis que 38% des arbustes présentaient des blessures localisées importantes sur leur écorce. Une deuxième évaluation complétée au début de la saison de croissance suivante a permis d'établir que seulement 40% des arbustes étaient en "bonne" condition à ce moment. Les blessures causées à l'écorce par la machine étaient toujours visibles. De façon globale, 72% des feuilles prélevées par la machine ont été récupérées par le système de collecte.
Mots-clés: argousier, récolte et collecte de feuilles, évaluation des dommages

INTRODUCTION

Sea buckthorn (*Hippophae rhamnoides* L.) is a multi-branched, thorny shrub that reaches 2-4 m in height at maturity. It is deciduous with narrow, silver-gray leaves (Li and Schroeder 1996). The fruit produced in late August is a yellow-orange berry that remains on the shrub all winter. Sea buckthorn has been used for centuries in Europe and Asia, but is only beginning to be recognized in North America for its nutritional and medicinal values.

Although the nutritional and medical properties of sea buckthorn berries are usually the focus of attention, sea buckthorn leaves also contain a variety of nutrients and bioactive substances (Morar et al. 1990; Mironov 1989). Sea buckthorn leaves are also a source of protein. Traditionally used in animal feed for rapid weight gain and a shiny coat (Schroeder and Yao 1995), sea buckthorn leaves also are dried for teas and processed for nutraceutical products.

One problem facing the sea buckthorn industry in Canada is the lack of mechanical harvesting equipment. In Asia, sea buckthorn berries and leaves are harvested by hand. In Canada, however, manual labour is either unavailable or economically prohibitive. Harvesting of sea buckthorn berries has been investigated around the world (Gaetke et al. 1991; Varlamov and Gabuniya 1990; Wegert and Wolf 1990; Gaetke and Triquart 1992, 1993; Olander 1995; Mann et al. 2001) and a berry harvester is currently being developed and tested by the authors. Harvesting of sea buckthorn leaves has not yet been reported.

This paper describes the design and performance of two mechanical leaf harvesters for sea buckthorn. In the summer of

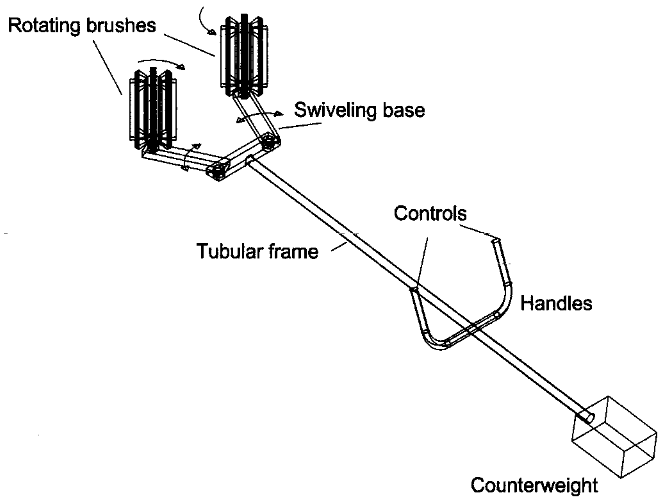

Fig. 1. Schematic of the hand-held prototype sea buckthorn leaf harvester. The harvester consisted of hydraulically-powered counter-rotating brushes (300 mm in length with 8 equally-spaced rows of interchangeable bristles) on the end of a tubular frame.

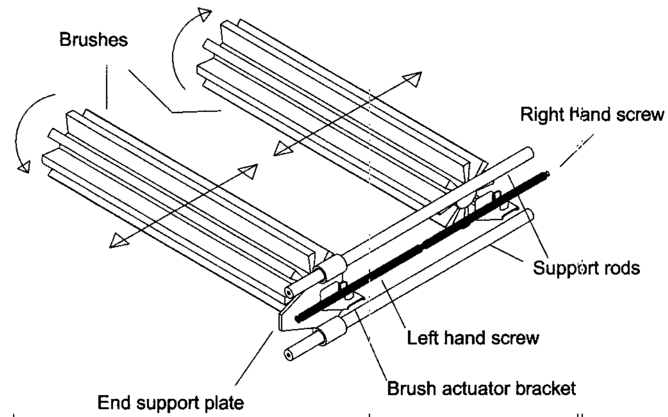

Fig. 2. Schematic of the brush head used on the trailer-mounted prototype sea buckthorn leaf harvester. Each brush head was 915 mm in length and consisted of 8 equally-spaced rows of interchangeable bristles. The distance between the counter-rotating brushes was adjusted using an electrically-powered motor connected to a lead screw with both right and left-hand threads.

2000, a hand-held prototype was fabricated and tested. In the summer of 2001, a trailer-mounted prototype was fabricated and tested. Harvesting trials were completed to assess the effectiveness of each prototype.

PROTOTYPE HARVESTERS

Hand-held prototype

The hand-held prototype consisted of a pair of hydraulically-powered, rotating brush heads at the end of a tubular, aluminum frame (Fig. 1). The brush heads extended upwards from the base of the machine and were 300 mm in length. The centre mandrel of each brush head was 50 mm in diameter and contained eight equally-spaced slots into which different types of bristles could be inserted. All bristles were 100 mm in length originally. The brush heads were connected to a base consisting of two arms that swivel relative to each other so that the distance between the rotating brushes could be adjusted during operation of the harvester. Controls were placed on the handles of the machine. The harvester was carried by a shoulder harness. A weight was attached to the frame behind the operator to counterbalance the weight of the brush head at the opposite end.

Trailer-mounted prototype

To overcome the problem with the excessive weight of the hand-held prototype, the functional brush heads were mounted onto a trailer using a 2.4-m long arm. The arm was able to rotate 360° and could be raised to a height of 2.6 m. As with the hand-held prototype, the centre mandrel of each brush head was 50 mm in diameter and contained eight equally-spaced slots into which different types of bristles could be inserted. All bristles were 100 mm in length originally.

Unlike the hand-held version, the brush heads were mounted horizontally. The brush heads were lengthened from 300 to 915 mm to allow an entire shrub to be harvested during a single pass. An electrically-powered motor connected to a lead screw with right and left-hand threads allowed the distance between the two counter-rotating brush heads to be adjusted (Fig. 2). In the open position, the brush heads were 0.5 m apart (bristle tip to bristle tip distance). In the closed position, the bristles were fully intermeshing. The harvester was manually controlled from an operator station near the front of the trailer.

A leaf collector was added to the trailer-mounted prototype to capture the leaves after they were removed from the shrub. A sheet-metal hopper was fabricated to enclose each brush head from both the top and the outside (Fig. 3). The vertical clearance was 250 mm and the horizontal clearance was 200 mm. Each hopper was attached rigidly to the brush head support, therefore, they moved with the brush heads when the distance between the

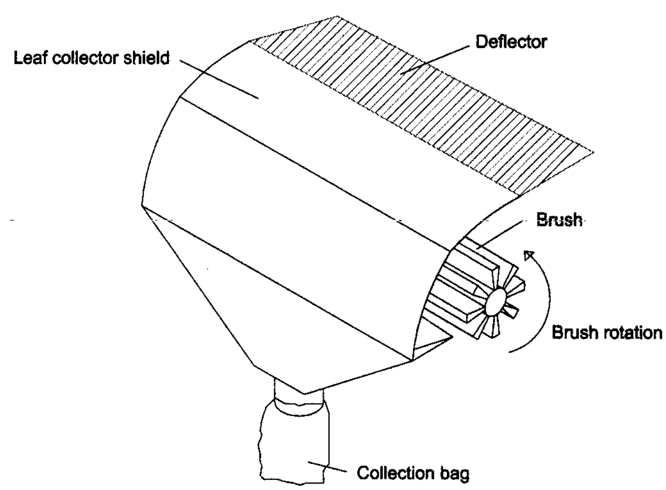

Fig. 3. Schematic of the leaf collection device attached to the brush head of the trailer-mounted prototype sea buckthorn leaf harvester. A sheet-metal hopper enclosed the rotating brush head. Leaves were captured in a collection bag at the bottom of the hopper.

heads was adjusted. A “deflector” made of 0.5-mm diameter polypropylene bristles was attached to the top edge of each hopper to prevent the loss of flying leaves. The deflector was designed with flexible bristles to prevent bark damage as the harvesting head moved through the canopy of the shrub. For experimental purposes, plastic bags were used to collect the leaves from the bottom of each hopper.

EXPERIMENTAL DESIGN

Hand-held prototype

Young (5-years old), unpruned sea buckthorn shrubs of the cultivar ‘Indian Summer’ located at the Prairie Farm Rehabilitation Administration (PFRA) Shelterbelt Centre, Indian Head, Saskatchewan were randomly selected for testing. All shrubs were approximately 2 m high with a maximum canopy diameter of approximately 1 m. A full factorial experimental design was used to test three types of bristles (0.7-mm diameter polypropylene, 1.0-mm diameter polypropylene and 1.5-mm diameter nylon; obtained from Power Brushes Inc., Toledo, OH), two rotational brush speeds (340 and 525 rpm measured in the “unloaded” condition), and three brush-head positions (“touching” with 240 mm between the axes of the rotating brushes, “intermeshed” with 210 mm between the axes of the rotating brushes, and “fully closed” with 180 mm between the axes of the rotating brushes). Each treatment was tested on a separate shrub. Two or three replicates of each treatment were completed on each of four harvest dates (July 5-7, 11-13, 25-26, and August 18, 2000). In this analysis, harvest date was not considered an experimental variable. To negate the effect of time of day, the first replicate of each treatment was completed in the morning; the second replicate was completed in the afternoon; and the third replicate was completed in the late afternoon/evening. The number of replicates completed on each harvest date varied due to inclement weather or mechanical problems with the harvester. The harvester was operated by two different individuals, but this was not considered an experimental variable.

Trailer-mounted prototype

Young (5-years old), unpruned sea buckthorn shrubs of the cultivar ‘Indian Summer’ located at the PFRA Shelterbelt Centre, were selected for testing. Shrubs of similar size (1.5-2.1 m high and 0.9-1.2 m wide) were selected. A full factorial experimental design was used to test two types of bristles (0.7 and 1.0-mm diameter polypropylene bristles) and two rotational brush speeds (350 and 500 rpm measured in the “unloaded” condition). Each treatment was tested on a separate shrub. Between three and five replicates of each treatment were completed for each of three harvest dates (July 10-11, 19-20, and August 16-17, 2001). In this analysis, harvest date was not considered an experimental variable. To negate the effect of time of day, replicates of each treatment were completed in a sequential manner (i.e., the first replicate of each treatment was completed first, followed by the second replicate of each treatment, etc). The number of replicates completed on each harvest date varied due to inclement weather or mechanical problems with the harvester. On the last two harvest dates, each shrub was harvested using two passes with the brush head.

EXPERIMENTAL PROCEDURE

Hand-held prototype

A tarp was spread on the ground between the machine operator and the shrub. After setting the prototype to the desired configuration, the operator used the prototype to strip leaves from the shrub for 40 s. The leaves were gathered from the tarp and placed in sealed plastic bags. Additional bags were used to gather any pieces of branch or stem that were removed during the harvesting process. The bagged material was frozen until sorting and analysis could be completed. The leaves were weighed on a wet mass basis and recorded as “harvest” while the stems and branches were weighed and recorded as “debris.” Testing had to be halted on several occasions because of high winds that blew the leaves off the collection tarp.

Trailer-mounted prototype

A tarp was spread on the ground around the shrub’s base. After inserting the desired bristles, the harvesting head was positioned with one brush head on either side of the shrub at the height where leaves first appeared. Before the brushes began to rotate, the brush heads were brought together until they were in full contact with the branches. At this point, rotation of the brushes was started. Using the hydraulic controls, the operator lifted the arm and simultaneously moved the brush heads together or apart to maintain contact with the shrub until the brush heads reached the top of the shrub. At the end of the trial, the brush heads were fully closed above the shrub. When a second pass by the brush head was desired (second and third harvest dates), the trailer was moved so that the brush head approached the shrub at an angle of 90˚ to the first pass.

Separate plastic bags were used to collect the material from the left hopper, the right hopper, and the tarp. The bagged material was frozen until sorting and analysis could be completed. The samples were sorted and weighed as “harvest” and “debris”. “Harvest” consisted of leaves, and “debris” was any other material removed from the shrub including bark, stems, and branches. Leaves collected from the tarp were considered as “harvest”.

A “damage key” was proposed by researchers of the PFRA Shelterbelt Centre, Indian Head, SK (Table 1). Two damage assessments were completed; one following the harvesting trials in the autumn of 2001 and one during the spring of 2002. The initial assessment was used to establish the damage inflicted by the harvester. The second assessment was used to determine whether the shrubs were able to recover from the damage inflicted by the harvester.

RESULTS and DISCUSSION

Criteria for assessment of harvester effectiveness

The effectiveness of the hand-held prototype was based on two factors: quantity of “harvest” (i.e., leaves) removed and quantity of “debris” removed. For the trailer-mounted prototype, the effectiveness was based on four factors, quantity of “harvest” removed, quantity of “debris” removed, damage to the shrub, and proportion of leaves captured by the leaf collection system. Ideally, the harvester should remove and collect a large quantity of “harvest”, remove a small quantity of “debris”, and do minimal damage to the shrub.

Table 1. Key used to assess the damage inflicted upon the sea buckthorn shrubs by the trailer-mounted prototype.

Descriptor	Key	Meaning
Branch damage	light	0-24% of branches damaged
	medium	25-74% of branches damaged
	heavy	75-100% of branches damaged
Bark damage	light	scuffing of bark
	medium	outer layer removed
	heavy	complete disruption of the vascular tissue
Leaf bud damage	light	0-24% of leaf buds damaged
	medium	25-74% of leaf buds damaged
	heavy	75-100% of leaf buds damaged
Overall condition of shrub	good	shrub visibly vigorous; no appreciable change in condition compared to control shrubs
	fair	shrub noticeably less vigorous than control shrubs, but no serious damage visible
	poor	shrub significantly less vigorous than control shrubs; serious damage present

Table 2. Rate of harvest (mean and standard deviation based on sample sizes ranging from 5 to 8) with the hand-held harvester for 2 brush speeds, 3 brush positions, and 3 bristle types.

"Unloaded" brush speed (rpm)	Brush position	Harvest rate (g/s)		
		0.7-mm diameter polypropylene bristles	1.0-mm diameter polypropylene bristles	1.5-mm diameter nylon bristles
340	touching	0.8 (0.3) (7)*	1.0 (0.2) (8)	2.7 (0.9) (7)
	partially intermeshed	1.2 (0.7) (6)	3.5 (1.7) (6)	4.6 (2.4) (6)
	fully intermeshed	3.7 (1.7) (8)	4.8 (1.3) (8)	6.0 (1.8) (8)
525	touching	1.7 (0.8) (7)	2.0 (0.8) (8)	5.4 (0.6) (8)
	partially intermeshed	4.4 (1.9) (6)	4.5 (1.5) (6)	6.4 (1.7) (5)
	fully intermeshed	5.2 (2.2) (7)	5.1 (2.1) (8)	10.5 (3.0) (6)

*First value in parenthesis is standard deviation, second value is sample size.

Table 3. Rate of debris removal (mean and standard deviation based on sample sizes ranging from 5 to 8) with the hand-held harvester for 2 brush speeds, 3 brush positions, and 3 bristle types.

"Unloaded" brush speed (rpm)	Brush position	Debris removal rate (g/s)		
		0.7-mm diameter polypropylene bristles	1.0-mm diameter polypropylene bristles	1.5-mm diameter nylon bristles
340	touching	0.1 (0.1) (7)*	1.0 (0.1) (8)	3.2 (4.4) (7)
	partially intermeshed	0.2 (0.4) (6)	0.2 (0.2) (6)	4.4 (3.8) (6)
	fully intermeshed	0.7 (1.4) (8)	0.9 (1.3) (8)	4.2 (3.0) (8)
525	touching	0.7 (1.1) (7)	0.2 (0.2) (8)	5.7 (4.5) (8)
	partially intermeshed	0.1 (0.2) (6)	1.4 (2.1) (6)	7.5 (5.6) (5)
	fully intermeshed	1.0 (0.8) (7)	1.6 (2.0) (8)	4.9 (2.7) (6)

*First value in parenthesis is standard deviation, second value is sample size.

Hand-held prototype

The mass of "harvest" removed from the shrubs, expressed as a harvest rate in g/s, for each combination of factors is presented in Table 2. The best harvest rate observed was 10.5 g/s using 1.5-mm diameter nylon bristles rotating at 525 rpm. There is limited evidence to suggest that the harvest rate is dependent upon the aggressiveness of the brush head. In this experiment, the aggressiveness changed due to the type of bristle used (i.e., larger diameter bristles were stiffer), the rotational brush speed (i.e., as the rotational speed increased, more energy was applied to the leaf canopy), and the brush-head position (i.e., as the spacing between the brushes decreased, the level of interaction between the brushes increased).

Statistical analysis using the Tukey-Kramer HSD test (α= 0.05) indicated that there were no significant differences in harvest rate between the 0.7 and 1.0-mm diameter polypropylene bristles, however, the harvest rate was significantly different (better) for the 1.5-mm diameter nylon bristles compared to both the 0.7 and 1.0-mm diameter polypropylene bristles. The Tukey-Kramer HSD test also indicated significant differences for both brush speed and brush position. Using "quantity of harvest" as the primary criterion, the hand-held harvester worked best with 1.5-mm diameter nylon bristles operated at a rotational speed of 525 rpm in a fully-intermeshed position.

The mass of "debris" removed from the shrubs, expressed as a rate in g/s, for each combination of factors is presented in Table 3. Statistical analysis using the Tukey-Kramer HSD test (α = 0.05) indicated that there were no significant differences in the rate of "debris" removal for the factors of brush position or brush speed. Significantly different (higher) "debris" removal rates were observed when the 1.5-mm diameter nylon bristles were used compared to the 0.7 and 1.0-mm polypropylene bristles. When expressed as a percentage of the mass of "harvest", the 0.7 and 1.0-mm diameter polypropylene bristles removed, on average, 16 and 17% "debris",

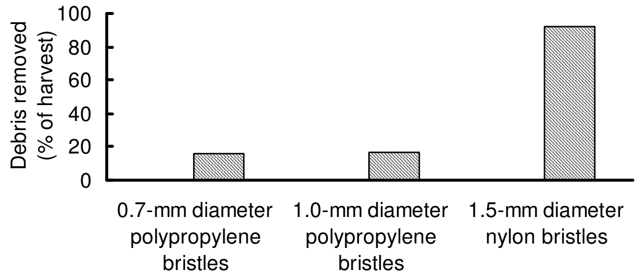

Fig. 4. Comparison of the mass of debris removed by the hand-held prototype sea buckthorn leaf harvester, expressed as a percentage of the mass of leaves removed, for three types of bristles.

Table 4. Mass of leaves removed (mean and standard deviation based on sample sizes ranging from 3 to 12) and estimated harvest rate for each of the 2 passes with the trailer-mounted leaf harvester for 2 brush speeds and 2 bristle types.

Bristle type	"Unloaded" brush speed (rpm)	1st pass		2nd pass	
		Harvest (g)	Harvest rate (g/s)	Harvest (g)	Harvest rate (g/s)
0.7-mm diameter polypropylene	350	113 (45) (12)*	3.8	82 (57) (7)	2.7
	500	189 (63) (11)	6.3	137 (66) (6)	4.6
1.0-mm diameter polypropylene	350	415 (207) (12)	13.8	280 (142) (6)	9.3
	500	510 (236) (9)	17.0	327 (103) (3)	10.9

*First value in parenthesis is standard deviation, second value is sample size.

respectively, compared to the 1.5-mm diameter nylon bristles which removed 92% "debris" on average (Fig. 4). The data suggest, therefore, that the 1.5-mm diameter nylon bristles should not be used because they remove too much "debris" which could create separation problems during the processing of the leaves. From the tests with the hand-held harvester, it can be concluded that the best results were obtained using 1.0-mm diameter polypropylene bristles operated at a rotational speed of 525 rpm in a fully-intermeshed position.

In addition to the recorded data, there were several other important observations made during the completion of these tests. Despite steps taken to minimize the mass of the harvester during the design process, it was too heavy for prolonged use. In addition to causing muscle fatigue, the harvester was also difficult to manoeuver. Branches tended to wrap around the rotating brushes. When this happened, the harvester pulled itself into the canopy. The operator then had to struggle to pull the harvester back out of the canopy. If not done quickly enough, large pieces of branches were broken off the shrub.

Trailer-mounted prototype

The mass of "harvest" removed from the shrubs during a single pass with the harvester ranged from 113 to 510 g (Table 4). Based on a review of video footage of the harvester in action, a single pass over a shrub required approximately 30 s. With this approximation, the harvest rate ranged from 3.8 to 17.0 g/s (Table 4).

Unlike the hand-held prototype, the effectiveness of the trailer-mounted prototype at removing leaves was not dependent on the rotational speed of the brushes (Tukey-Kramer HSD test, $\alpha = 0.05$). The harvest rate was significantly different (Tukey-Kramer HSD test, α=0.05) when the bristle diameter was compared (i.e., the 1.0-mm polypropylene bristles removed significantly more leaves). The differences between rate of debris removal were found to be significant for both bristle diameter and brush rotational speed (Tukey-Kramer HSD test, $\alpha = 0.05$) (Table 4). More debris was being removed when the larger-diameter bristles were being used and when the brushes were rotating at a higher speed.

The results from the trailer-mounted harvester suggest that a compromise must be achieved. The 1.0-mm polypropylene bristles increased the yield of leaves, but they also removed more debris. Debris removal can be limited by operating the harvester at the lower rotational speed. Therefore, a possible conclusion is that the harvester should be operated with 1.0-mm polypropylene bristles at a rotational speed of 350 rpm.

During the harvesting trials, it was visually observed that leaves were being removed from only the parts of the foliage that were in direct contact with the brush heads. Apparently, the bristles were not able to penetrate into the foliage. To increase the percentage of leaves removed from the shrub, therefore, multiple passes from different angles may be necessary. There were no significant differences in harvest rate (t-test, $\alpha = 0.05$) between the first and second passes, except when the 1.0-mm polypropylene bristles were used at a rotational brush speed of 500 rpm (Table 5). For this combination, significantly fewer leaves were removed on the second pass. These results suggest that a second pass with the leaf harvester is worthwhile. Further research is needed to determine the point at which subsequent passes with the leaf harvester cease to be feasible in terms of quantity of harvest. Unfortunately, there were no significant decreases in the removal of debris from the first to the second pass (t-test, $\alpha = 0.05$) (Table 5).

Based on subjective evaluation of the shrubs during the autumn of 2001 using the "damage key" presented earlier, the harvester did damage the shrubs. Damage to the branches and leaf buds was minimal in the majority of cases (Fig. 5), but 38% of the shrubs had localized regions of heavy bark damage where the vascular tissue was disrupted. This could be a cause for concern because it provides a means of entry for both insects and disease. Most likely, the bark damage was caused by sharp edges present on the brush heads. The brush heads will need to be redesigned to correct this problem. Overall, 87% of the shrubs were considered to be in "good" condition and 13% were considered to be in "fair" condition.

Table 5. Mass of "debris" removed (mean and standard deviation based on sample sizes ranging from 3 to 12) and estimated debris removal rate for each of the 2 passes with the trailer-mounted leaf harvester for 2 brush speeds and 2 bristle types.

Bristle type	"Unloaded" brush speed (rpm)	1st pass		2nd pass	
		Harvest (g)	Harvest rate (g/s)	Harvest (g)	Harvest rate (g/s)
0.7-mm diameter polypropylene	350	4 (6) (12)*	0.1	2 (2) (7)	0.1
	500	10 (12) (11)	0.3	10 (9) (6)	0.3
1.0-mm diameter polypropylene	350	22 (30) (12)	0.7	9 (8) (6)	0.3
	500	118 (124) (9)	3.9	35 (41) (3)	1.2

*First value in parenthesis is standard deviation, second value is sample size.

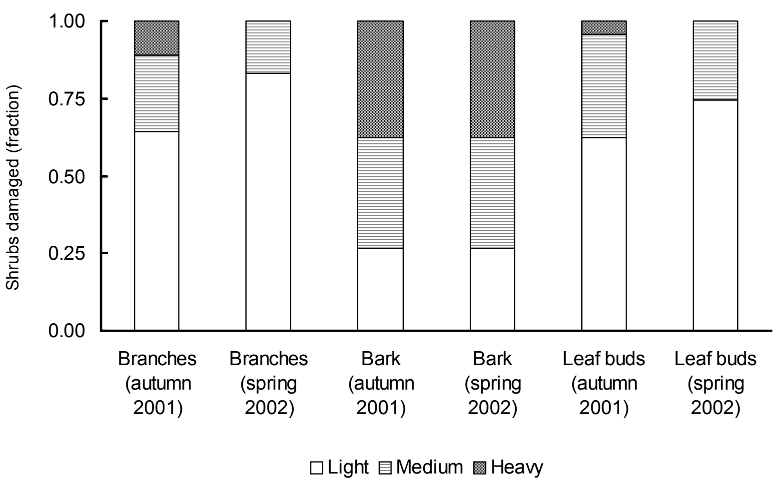

Fig. 5. Percentage of shrubs experiencing branch, bark, and leaf bud damage in the autumn of 2001 immediately following the harvesting trials and in the spring of 2002 at the beginning of the growing season following the harvesting trials.

When the shrubs were re-evaluated in the first week of June 2002, 19 of the 47 shrubs were developing slowly. Only 40% of the shrubs were considered to be in "good" condition (the remaining 60% were classified as being in "fair" condition). It is not known whether this was due to being mechanically harvested in the previous year or whether it was due to climatic conditions because many shrubs not harvested (i.e., control shrubs) were also developing slowly. Despite the lack of vigor, damage to the branches and leaf buds was minimal in the majority of cases (Fig. 5). It should be noted, however, that all of the bark wounds were still visible.

Table 6. Percentage of leaves captured by the collector for different combinations of brush speed and bristle diameter.

"Unloaded" brush speed (rpm)	Bristle diameter (mm)	Leaves captured (%)
350	0.7	80
	1.0	75
500	0.7	71
	1.0	67

Leaf collection in the hoppers decreased from 82% using polypropylene bristles of 0.7-mm diameter rotating at 350 rpm to 67% when using polypropylene bristles of 1.0-mm diameter rotating at 500 rpm (Table 6). Because more energy was given to the leaves when the brushes rotated at high speeds, the trajectory of the flying leaves was altered. Consequently, a smaller proportion of the leaves was collected at high rotational speeds. The leaves that were not collected tended to be spun around the brushes and out the bottom where the hoppers did not reach. Others were lost out the front of the brushes.

In addition to the data that were collected, a number of other comments are relevant to the evaluation of the trailer-mounted prototype. As a trailer-mounted unit, the harvester lacks maneuverability. If multiple harvesting passes at different angles are necessary, this issue will need to be addressed. Also, modifications to the brush head are required. The two rotating brush heads must open wider to accommodate larger shrubs. Ideally, the simultaneous closing and raising of the brush head should be automated. This would allow the harvester to function consistently from shrub to shrub. In an orchard setting, it is likely that the shrubs would be pruned to relatively constant dimensions.

CONCLUSIONS

A brush-type machine was developed as a mechanical harvester for sea buckthorn leaves. To accommodate the necessary moving parts, the hand-held prototype became too heavy for prolonged use. A better alternative was to mount the harvesting unit on a trailer, although this configuration had limited maneuverability. The variables important in the design of a brush-type leaf harvester include the type of bristle used, the rotational speed of the brush head, and the presence of a resistive force offered either by a second brush head or by the shrub itself. With the hand-held prototype, the best harvest rate observed was 10.5 g/s using 1.5-mm diameter nylon bristles rotating at 525 rpm. A harvest rate of 17.0 g/s was observed with the trailer-mounted prototype using 1.0-mm diameter polypropylene bristles rotating at 500 rpm. Generally, the harvest rate increased as the aggressiveness of the brush head increased. In terms of debris removal, nylon bristles with a diameter of 1.5 mm were too aggressive because they removed almost as much debris as leaves (measured on a mass basis). Polypropylene bristles with a diameter of 1.0 mm operated at either 350 or 500 rpm yielded acceptable results. Based on preliminary assessment of the damage caused by the trailer-mounted harvester, 87% of the shrubs were considered to be in "good" condition although 38% of the shrubs had localized regions of severe bark damage. During a subsequent damage assessment at the beginning of the next growing season, only 40% of the shrubs were considered to be in "good" condition due to slow development. The severe bark damage was still visible. Overall, the leaf collection system captured 72% of the leaves that were removed by the harvester.

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