PERFORMANCE AND ECONOMIC ANALYSIS OF A SELECTIVE ASPARAGUS HARVESTER

C. D. Clary, T. Ball, E. Ward, S. Fuchs, J. E. Durfey, R. P. Cavalieri, R. J. Folwell

ABSTRACT. *Developing and adopting harvesting systems for asparagus provides an important means to address increasingly urgent industry concerns including the rising cost of labor and global competition. These mechanical systems will help to maintain U.S. and particularly, the state of Washington's position in national and international markets. Minimum wage will increase to over $7.93/h in 2007 in the state of Washington, and changes in international trade policies have presented significant challenges to the asparagus industry in the state of Washington. The asparagus industry has been impacted by imports from Peru. In addition to foreign competition, labor for hand harvesting asparagus has become scarce, particularly at the end of the season. It is common for fields to be abandoned prematurely due to lack of labor. This has prompted the industry to evaluate mechanical harvesting in order to reduce production costs associated with hand labor and extend the harvest window when hand labor is not available. In the spring of 2006, four selective mechanical asparagus harvesters were evaluated (Oraka, New Zealand; Larsen, Wash.; HiTek, Ala.; Geiger Lund, Calif.). The most successful harvester was a single row asparagus harvester prototype developed by Geiger Lund Harvesters (Stockton, Calif.). The harvester head employs parallel pairs of counter-rotating "rollers" that engage asparagus spears that have reached a specified height. As the machine moves down the row, the optical system senses a spear of the selected minimum height and actuates a cutting system that drives the closest blade into the soil at the base of the spear. The spear is pulled through counter-rotating rollers onto a backstop and conveyer that transports spears to the rear of the harvester. Economic analysis indicates that a four-row harvester must recover 70% of hand-harvested yield to be break even. It was concluded that with further improvements to the harvester, it would be successful at achieving an efficiency of 70% to 80% compared to hand harvesting. Damage to the spears was not significant.*

Keywords. *Asparagus, Harvesting, Economics.*

Asparagus is a specialty crop that requires intensive labor to harvest, pack, and process. Asparagus spears emerge from a perennial crown on a daily basis and the season can last up to 3 months in the state of Washington. Washington growers use a perennial flat bed crown culture unlike crowned, raised beds used in other growing regions. Since the spears emerge daily and grow several days before reaching a marketable length, there are spears of various lengths each day. The hand crew selects spears long enough for market each day and cuts and gathers them. Over the entire season, an asparagus field can produce as much as 6,700 kg/ha, however this production takes place over 10 to 12 weeks meaning daily yields are about 560 to 673 kg/ha. Harvest is a very labor-intensive practice.

Beginning early in the 1900s, there were numerous efforts to reduce labor by mechanizing the harvest process. Asparagus harvester testing and experimentation was aggressive in the 1960s and '70s. Harvester research decreased in the 1980s, but interest resumed in the 1990s due to increased labor costs, concerns over the supply of labor, and technological developments (Marshall, 1994). These research efforts were unsuccessful due largely to damage to emerging spears, low pay weights as compared to hand-harvested asparagus, negative effects on yields, and the cost of mechanical harvesters.

Hand harvesting is labor intensive and is performed by workers paid by piece rate, but must earn a wage equal to or above the Federal or state minimum wage. An asparagus grower typically pays 50% of total revenue on harvest expenses. In the United States, 85% of asparagus production is in California and Washington where wage rates exceed the national average. Washington has the nation's highest minimum wage rate, which will increase to $7.93/h in 2007. Mexico and Peru are the primary competitors in the U.S. market. These countries pay rates as low as $0.40 to $0.60/h ($4-6/day). To remain competitive, the U.S. asparagus industry will need to mechanize the harvesting process. Mears et al. (1977) noted that if hand costs increased relative to the selling price of asparagus, then mechanization was necessary.

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Previous attempts to mechanize have been unsuccessful due primarily to decreased yields accompanied with higher costs. A study by Stout et al. (1967) concluded that a harvester must return a high quality yield and keep losses to a minimum to outperform hand harvesting. Despite the conclusion, limitations of mechanical harvesters continued related to the inability of the harvesters to cost effectively cut spears without damaging the asparagus. A leading cause of reduced yield levels is that mechanical harvesters had low product recovery and a product of reduced quality (Brown, et al. 1983). To date, this has been true for both selective and nonselective harvesters.

Early harvester research demonstrated that nonselective harvesters were typically more economical (Kepner, 1959; Stout and Kline, 1968). Technology during this period was not available to develop selective harvesters capable of harvesting asparagus for the fresh market. Recent research identified that nonselective harvesters cut spears too short for the fresh market and tend to damage emerging spears and generate a mixed product of spears, weeds, and other debris (Kasmire, 1983). For nonselective harvesters to be commercially viable, a new market for the shorter spears would be needed, or an asparagus variety that grows spears at a uniform rate.

Technology has advanced to the point where selective harvesters now have potential commercial viability especially since the minimum wage has increased significantly. Machine vision is allowing the agricultural sector to handle crops differently than was previously possible. A study in 1990 describes machine vision to identify harvestable spears (Humberg and Reid, 1990). Despite the success, no known harvester is using the specific technology developed in the study. Since then, developments have improved at combining a mechanical system with spear detection.

A 1995 study summarizes the more recent asparagus harvesting technology including two selective (CAMIA, Australia and Haws, Mesa, Wash.) and two non-selective harvesters (Snapper, Mich. and Swather, Pasco, Wash.). Though the harvesters proved not to be acceptable from an economic perspective, Folwell and Worley (1995) reported slight improvement in the grades for the mechanically harvested asparagus and therefore increased feasibility. The selective harvesters in the study used more advanced technology than previously evaluated and performed well selectively harvesting the asparagus. The primary reason the harvesters were not economically beneficial was the high costs of harvesting. The two harvesters, Haws and CAMIA, had harvesting cost of 94% and 77% above that of hand harvesting, respectively (Folwell and Worley, 1995). A report from the developers of the CAMIA machine noted that reducing the costs of the harvester would increase the likelihood of an economically feasible machine. Obtaining harvester expenses close to 50% of revenue, as for hand harvesting, would increase viability (Arndt et al., 1997).

Economic Considerations

To determine the commercial viability of a mechanical harvester, it must meet several criteria. First, the harvested product must be of acceptable quality for use by fresh packers and processors. Damage to the asparagus spears makes the product unusable. Second, the harvester must do an adequate job of cutting spears, while maintaining a clean field. It may not be practical to regularly follow the harvester with a cleanup crew to remove missed spears and weeds. Finally, if the machine is able to meet the above two requirements, it must do so in a profitable manner. If the selective harvester meets these three criteria, then it is a viable alternative to manually harvesting asparagus.

The purpose of this study was to evaluate the Geiger Lund selective harvester for efficiency and economic profitability (Geiger Lund, Stockton, Calif.). To accurately determine the economic feasibility of mechanical harvesting, the analysis must account for reduction in crop value as well as the decrease in harvesting costs (Brown, et al., 1983). A cost-benefit analysis was conducted to evaluate the product recovery the selective harvester will need to operate at in order to return a positive benefit to the grower. The expense of financing and operating the machine was included in the analysis as well as the savings from reduction in employees, supervisors, and labor taxes.

Harvester Description

A single harvester head is mounted on the front of a motorized carrier unit and consists of four components: spear detection, spear cutting, spear capture, and harvester head height control (fig. 1). Spear capture employs parallel pairs of counter-rotating rubber rollers that engage asparagus spears that have reached a specified height, which is usually 23 cm. The cutting mechanism consists of 12 cutting blades that cover the width of the row (figs. 2a and 2b). Each blade is 5.7 cm wide and attached to a pneumatically operated cylinder. The optical system uses two pulsed lasers to detect asparagus spears. The upper laser is mounted at 23 cm to detect spears ready for harvest. The lower laser is used to determine the location of the spear at ground level in order to time the cut. There are 12 optical detectors, each dedicated to a cutting blade. When a detector senses a spear of the selected height as the harvester moves down the row, the cutting system drives the closest blade into the soil at the base of the spear. The cutting sequence consists of a pulse of compressed air that extends the blade to cut the spear. When the cylinder's piston approaches a fully extended position, compressed air is injected to slow the piston and withdraw the

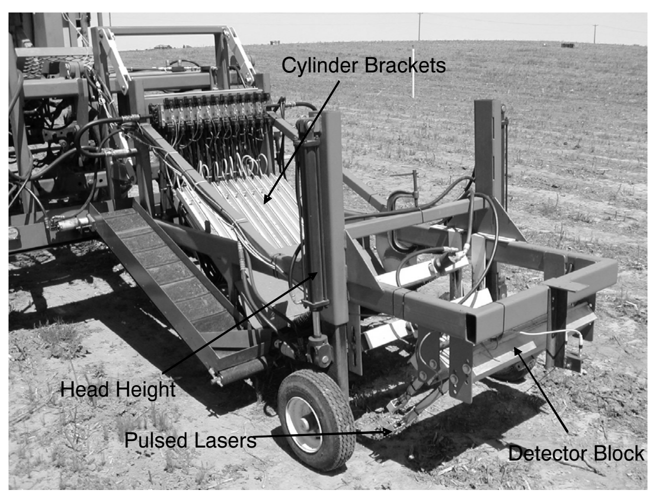

Figure 1. Geiger Lund selective mechanical harvester head.

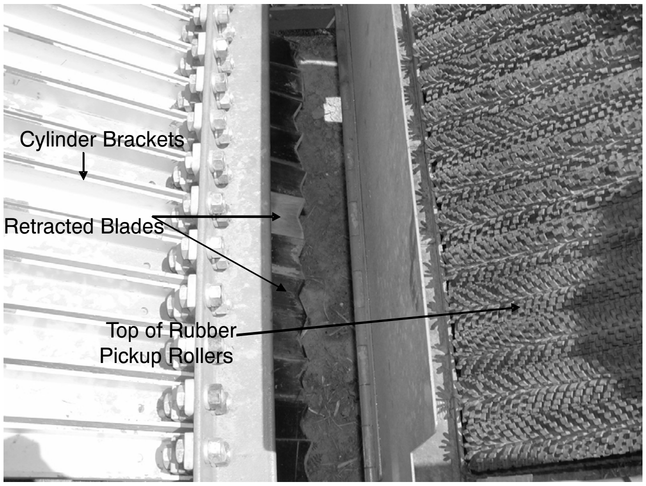

Figure 2a. Top of rubber pickup rollers (on right) and retracted cutting blades on the Geiger Lund harvester.

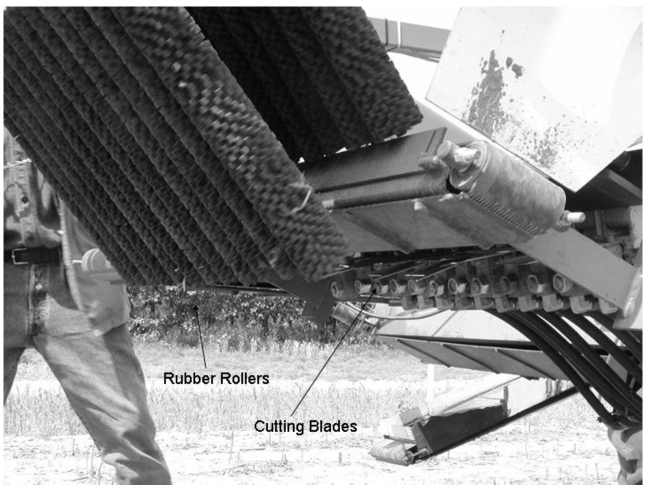

Figure 2b. Bottom view with the Geiger Lund harvester header in a lifted position.

blade rapidly. The cut spears are pulled through the counter-rotating rollers onto a backstop and conveyer that transports spears to a grading station at the rear of the harvester. The header included the use of a bed height sensor to account for variations in the height of the asparagus bed. Guide wheels and hydraulic cylinders control head height.

Materials and Methods

Estimated Mechanical Harvester Costs

Although the trials using the selective harvester used a one-row header, a commercial harvester would use four headers to harvest four rows. Cost for a complete four-row harvester is estimated to be $90,000. A typical Farm Credit Services loan would finance 80% of the cost of the harvester at an interest rate of 7.5% over 5 years for a purchase of this type of machinery. The annual cost, including principal and interest is $17,795.86. Besides the cost of financing to purchase the harvester, cost of operation includes the labor necessary to operate the harvester, fuel for the 50-hp tractor, and maintenance.

To determine the benefits of a harvester, it is assumed that it operates for 16 h/day. One driver and two packers on the back of the harvester are necessary. Wage rate for the packers is based on the Washington 2007 minimum wage of $7.93/h. The hourly rate is increased by 26% to $10.00/h to account for all additional expenses incurred by the employer including housing and mandatory deductions like Social Security and Medicare. The driver is paid $15.00/h, which also includes employee expenses.

Assumed ground speed is 3.8 km/h. At this speed, a four-row harvester could harvest up to 28 ha/day, assuming 16-h days and a field efficiency of 85%, equivalent of harvesting at 3.2 km/h. Based on a fuel price of $0.79/L and a 16 h/day, a fuel expense would be $85.33/day. The annual harvester maintenance is anticipated to be $1,500 -- a value estimated by the manufacturer.

Mechanical Harvester Evaluation

A commercial flat bed asparagus field near Pasco, Washington, was leased for the asparagus harvester trials conducted 24 April to 14 June 2006. The field contained two asparagus varieties. The south half of the field was a 5-year old Del Monte asparagus variety and the north half of the field was Green Giant, also in its fifth year of production. The experimental plot design consisted of 19 rows 298 m long on 101-cm centers covering an area of about 0.635 ha. Rows 1-3 were designated for practice and machine setup. Rows 4-19 were randomized and used for evaluation of the harvester. Eight randomly selected rows were mechanically harvested and eight were hand harvested in each asparagus variety resulting in two varieties, two harvest method, replicated eight times. The plots included 7.62-m buffers at each row end and a 9.14-m buffer down the row between the two varieties.

The harvested asparagus from each row was graded into three categories based on Washington state grading guidelines. This included: (1) useable undamaged product greater than 20.32 cm in length with at least 17.78 cm of the spear showing green, (2) useable undamaged product less than 20.32 cm useable for processing, and (3) culls, which included debris, damaged product and seedy asparagus. The data were analyzed using Analysis of Variance (Minitab).

To determine harvester efficiency within the row, a researcher walked behind the harvester and collected all the useable asparagus ($\geq$20 cm) that were not collected by the harvester. This included collateral damage to young emerging spears not yet of a useable length that were cut by the harvester and remained in the field. These would have been "tomorrow's spears" that were in close proximity to the marketable spear that was cut. Other loss included spears measuring 23 cm or taller left in the field that showed no signs of being detected and cut by the harvester. These were recorded as missed spears. Spears that had been cut but not picked up due to a poor cut were labeled side cuts and stringers. Stringers were spears that were not cut all the way through the spear and thus were not picked up by the harvester. In the control plots, spears were cut by hand and the product was put into bags for grading.

Damage Evaluation

A significant concern with mechanical harvesting asparagus is the potential for damage to the spears due to the mechanical action of cutting, pickup, and transport. It is possible to detect spear injury by evaluating several critical attributes of asparagus. The spear tip is the most delicate part of the spear and the first area to show symptoms of injury. The tip usually begins to dry and the braches feather. Another symptom is the spear becomes limp within a week due to premature water loss and associated low turgidity. The percent fiber content of asparagus is another attribute frequently used to measure the quality of asparagus. Spear damage causes respiration rates to increase and tends to increase consumption of carbohydrates within the spear. Low levels of carbohydrates initiate senescence and increase the formation of fiber and lignin in the spear.

Asparagus was harvested in May and June and stored for two weeks at 2°C prior to quality evaluation. In all tests, three samples of about 200 gm of asparagus were used. Attributes recognized as having a major influence on asparagus quality were evaluated for the mechanically and hand-cut asparagus, and included percent fresh weight loss, rate of respiration, fiber analysis, and physical appearance of the spears.

Results and Discussion

Economic Analysis

Total daily cost of operating the harvester, including the financing, labor, fuel, and maintenance expense is $14.94/ha based on the assumptions in this study. If the machine harvests a yield of 4,480 kg/ha then the cost is $0.49/kg (table 1). As harvester yield increases, cost per kilogram of harvested product declines. At 5,600 kg/ha the cost is $0.40/kg. Growers pay manual cutters by piece rate. An average value as reported by several Washington asparagus producers is currently $0.46/kg, which does not include the labor taxes (unemployment, social security, etc.) and housing expenses that the producer incurs.

Table 1. Harvesting cost per kilogram by the selective harvester.

Mechanically Harvested (kg/ha)	($/kg)
3360	$ 0.66
3584	$ 0.62
3808	$ 0.58
4032	$ 0.55
4256	$ 0.52
4480	$ 0.49
4704	$ 0.47
4928	$ 0.45
5152	$ 0.43
5376	$ 0.41
5600	$ 0.40

The break-even analysis indicated the yield a machine must harvest to provide a profit of an equal amount to the grower compared to hand harvesting. The savings included the reduction in the expense of the hand labor (wage, labor taxes, housing expense), the costs associated with minimum wage supplementation and the elimination of the supervisor (Minimum wage supplementation is the money needed to bring the manual cutters revenue up to the Washington state minimum wage level for cutters paid piece rate that do not earn an amount equal to minimum wage.). New expenses the producer would incur include the cost of operating the harvester (fuel, financing, labor, etc.) and the lost revenue of missed spears. It was assumed that the grower pays the manual cutter $0.46/kg, and that the supervisor earns $0.02/kg. The labor tax, which includes social security, unemployment, and worker's compensation, was $0.07/kg and the labor housing expense was $0.04/kg. The minimum wage supplementation was assumed to be $0.07/kg. The price received by the grower for the loss in yield would be $1.06/kg, when the harvested yield by the machine is below the harvested yield of the manual cutters.

At a baseline yield of 6,160 kg/ha of hand-harvested asparagus, the machine must harvest 4,368 kg/ha to generate a positive return of $2.75 per ha/day (table 2). Generally, the mechanical harvester must harvest at least 70% of the product that a hand crew generates to provide a return to the grower. If the machine harvests less, the grower is better off using hand harvesting, considering the assumptions used in this study.

Harvester Efficiency

In-Row Efficiency Evaluation

This evaluation determined the disposition of harvestable spears in the mechanically harvested rows (table 3). On average, the machine harvested nearly 70% of the product that was of marketable height and diameter; dropped product accounted for about 10%, missed product was 12%, and stringers/side cuts about 10%. This analysis indicated the need to reduce the amount of stringer/side cuts and early cuts to improve efficiency. Further, improving the pickup unit could reduce the amount of dropped spears, increasing efficiency and performance. The missed spears were

Table 2. Cost savings of using a selective harvester compared to manual cutting based on corresponding yields ($/ha/day).

kg/ha using a Selective Harvester	kg/ha by Manually Harvesting								
	5488	5712	5936	6160	6384	6608	6832	7056	7280
3696	($4.74)	($6.19)	($7.65)	($9.11)	($10.56)	($12.02)	($13.48)	($14.93)	($16.39)
3920	($0.79)	($2.24)	($3.70)	($5.16)	($6.61)	($8.07)	($9.53)	($10.98)	($12.44)
4144	$3.17	$1.71	$0.25	($1.20)	($2.66)	($4.12)	($5.58)	($7.03)	($8.49)
4368	$7.12	$5.66	$4.20	$2.75	$1.29	($0.17)	($1.62)	($3.08)	($4.54)
4592	$11.07	$9.61	$8.15	$6.70	$5.24	$3.78	$2.33	$0.87	($0.59)
4816	$15.02	$13.56	$12.10	$10.65	$9.19	$7.73	$6.28	$4.82	$3.36
5040	$18.97	$17.51	$16.05	$14.60	$13.14	$11.68	$10.23	$8.77	$7.31
5264	$22.92	$21.46	$20.00	$18.55	$17.09	$15.63	$14.18	$12.72	$11.26
5488	$26.87	$25.41	$23.96	$22.50	$21.04	$19.59	$18.13	$16.67	$15.21
5712	$30.82	$29.36	$27.91	$26.45	$24.99	$23.54	$22.08	$20.62	$19.17
5936	$34.77	$33.31	$31.86	$30.40	$28.94	$27.49	$26.03	$24.57	$23.12

Table 3. Disposition of mechanically harvested asparagus: harvested, detected but dropped, not detected and missed, and partially cut and not harvested.

	Del Monte								
Category	6 June	7 June	9 June	10 June	11 June	12 June	14 June	7-Day Avg.	Std Dev.
Net wt. harvested	64%	61%	66%	77%	75%	75%	67%	69%	0.059
Dropped product	11%	15%	8%	9%	10%	10%	5%	10%	0.027
Missed product	16%	11%	9%	5%	8%	6%	18%	11%	0.045
Stringers/side cut	9%	13%	17%	9%	7%	9%	10%	11%	0.031

	Green Giant								
Category	6 June	7 June	9 June	10 June	11 June	12 June	14 June	7-Day Avg.	Std Dev.
Net wt. harvested	70%	58%	70%	79%	69%	76%	70%	70%	0.061
Dropped product	8%	11%	5%	10%	12%	9%	8%	9%	0.023
Missed product	16%	12%	14%	7%	10%	9%	15%	12%	0.032
Stringers/side cut	6%	19%	11%	4%	9%	6%	7%	9%	0.046

detected by the optical system; however the cutting blade was not activated. This was due to mechanical problems with pneumatic valves.

Mechanical Harvester Yield vs. Hand Yield

In this evaluation, the daily pay weight was calculated for rows harvested by hand and machine. The total pay weight for the mechanical harvester was compared to the manual cutter to determine the efficiency of machine versus hand. Economic analysis for a four-row harvester has indicated that the harvester must recover 70% of what a hand crew harvests in order to be economically feasible based on a field yielding 6,160 kg/ha over the harvest period. The multiple row harvester would not be developed until the single header design performs to these specifications. From 3 June to 14 June 2006, the average pay weight of the harvester was about 50% of the pay weight harvested by the hand crew (fig. 3). There was a significant difference in yield ($p = 0.05$) between the yield of the hand and mechanically harvested rows.

Analysis of the data indicated there were spears that were successfully detected and cut, but were not captured in the pick up unit. This included side cut spears that were not fully cut and spears that were dropped, or not captured in the rollers. This analysis indicated the harvester successfully detected and cut an average of 66.4% and 68.5% compared to hand harvesting (fig. 4) which is close to the target of 70% of hand harvest. Further improvement of the pickup mechanism is needed.

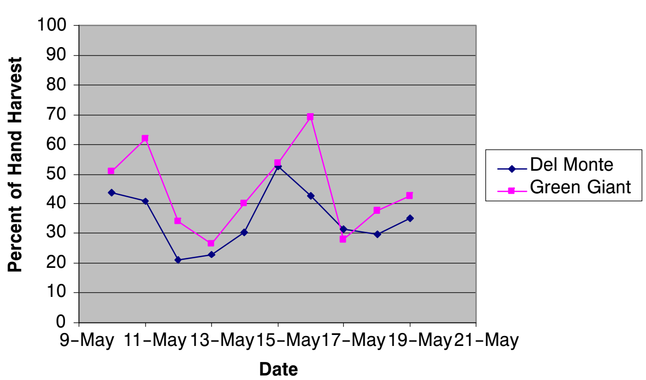

Figure 3. Percentage of pay weight harvested and collected by the harvester compared to hand harvesting. Harvester yield was significantly lower than hand harvesting (p = 0.05). Standard error = 3.11.

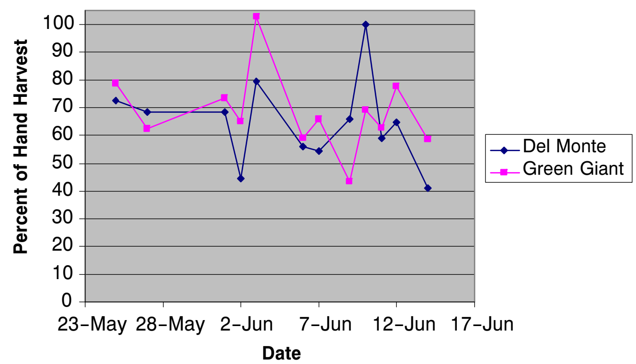

Figure 4. Percent of pay weight cut by the harvester compared to hand harvesting. This includes useable spears that were detected and cut but not picked up by the harvester (Plot 1 - Del Monte, Plot 2 - Green Giant). Harvester yield was significantly lower than hand harvesting (p = 0.05).

Damage Evaluation

Fresh Weight

Since asparagus is comprised of about 92% water, it requires immediate storage at cool temperatures to reduce transpiration and water loss. There were minimal differences detected in fresh weight loss, although the mechanical harvester had slightly less weight loss than hand-harvested asparagus for both harvest periods. The Geiger Lund mechanically harvested asparagus lost about 3.0% and hand cutting lost 3.5% in fresh weight in May (fig. 5). Mechanical harvesting of asparagus had no detrimental effect on weight loss, and in fact, may even reduce the amount of weight loss. Lower weight loss of mechanically harvested asparagus could be related to the mechanically cutting the spears below ground, which allows whiter portion of the spear intact. The white portion may be functioning as a small moisture reserve or a stop that reduces transpiration at the spear tip.

Respiration Rate

Asparagus usually has a high respiration rate immediately after harvest followed by a gradual decline for a period of 5 to 8 days. Respiration rate is also affected by mechanical damage so that older or damaged asparagus will have a lower rate of respiration than fresh cut asparagus. The respiration rate was determined by monitoring the O_2 and CO_2 levels for 4 days (fig. 6). The mechanically harvested asparagus

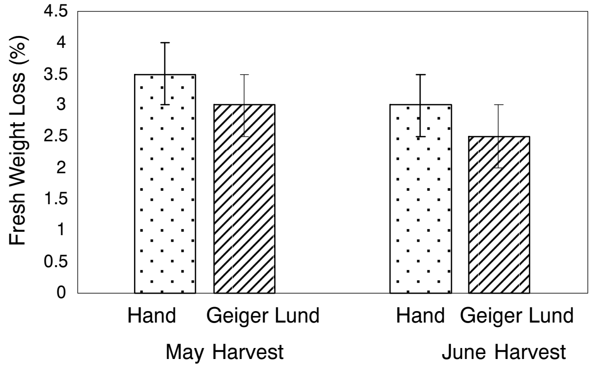

Figure 5. Fresh weight loss of mechanically and hand-harvested asparagus after a two-week period. Overlapping bars indicated no significant difference (p = 0.05).

respiration rate was slightly higher than hand-harvested asparagus. These results confirm that mechanically harvested did not cause a decrease in asparagus quality.

Visual Appearance

The mechanically and hand-harvested asparagus were assessed for physical appearance after two weeks in cold storage. Asparagus from both appeared free from symptoms of deterioration. The spears of the mechanically and hand-harvested asparagus showed almost no signs of tip feathering (fig. 7), tip rot, or stem basal decay. Spear color was mostly green with the exception of slight yellowing of a few spears, which indicates a small loss of chlorophyll. Spear tips showed virtually no feathering and had dark green with some purple color due to accumulation of anthocyanin. The primary difference found between mechanically and hand-harvested asparagus was that the harvester caused light damage to some spear stems. However, the spear tips did not appear to be damaged. Furthermore, spear damage was inconsistent among spears, which made it difficult to establish a relationship between mechanical harvesting and spear diameter, height, or time of harvest.

Summary

Numerous efforts have been made throughout the past 100 years to develop a mechanical means to harvest asparagus. There have been attempts with both selective and non-selective mechanical harvesters. Increased competition from international markets and the constant rise of wage rates in the asparagus producing states is damaging the U.S. asparagus industry. Mechanically harvesting asparagus is a viable alterative to maintain the United State's competitiveness. Currently, the Geiger Lund machine has demonstrates potential.

This study identifies the level the harvester must operate at to achieve commercial viability. An economic evaluation demonstrates the selective harvester must harvest approximately 70% to 80% of what a manual crew would harvest to provide an economic benefit to the grower. If the selective harvester can harvest a quality product efficiently, then it is possible the asparagus industry will adopt the technology. This efficiency could be further improved if the harvester used more than four heads to harvest more rows of asparagus in each pass through the field.

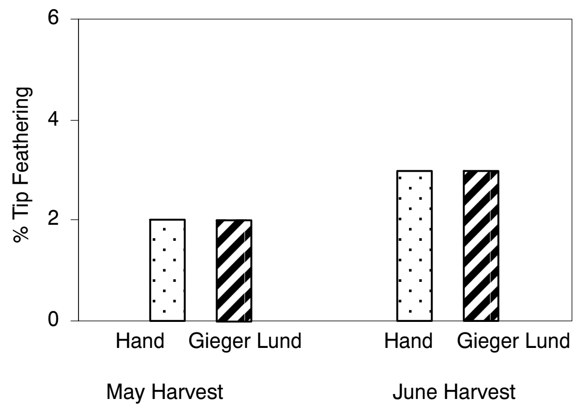

Figure 7. Average tip feathering of mechanically and hand-harvested asparagus after two weeks in cold storage. No significant difference (p = 0.05) in harvest method at each harvest.

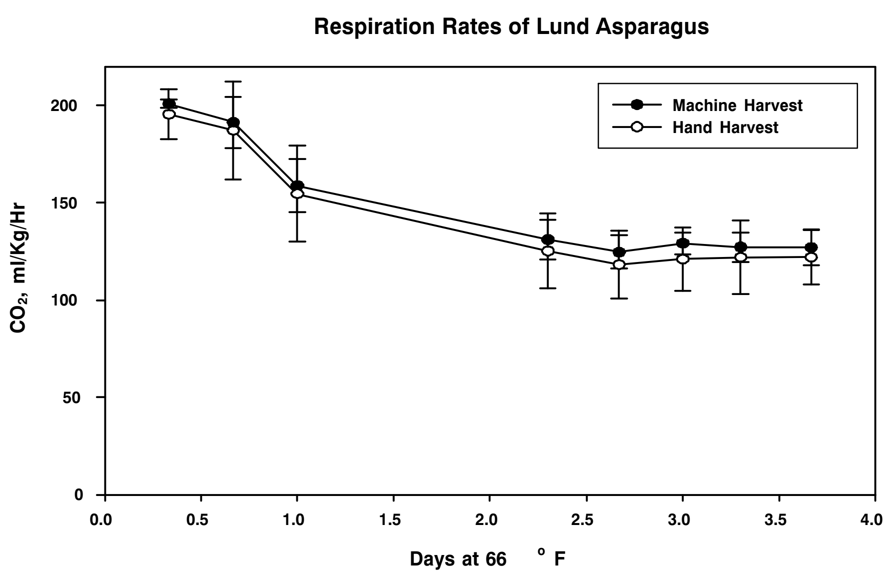

Figure 6. Respiration rate of mechanically and hand-harvested asparagus.

It is possible that the payable yield per hectare can be reduced using a mechanical harvester and still provide an economic benefit to the grower. Reduction in the labor required to manually harvest asparagus provides greater financial benefit than the expense of lost revenue from using a mechanical harvester. If the machine harvests less than 70% to 80% payable yield then a grower is better off using the hand crew for harvest. It is anticipated that if the pickup mechanism on the harvester can be improved, the harvester efficiency will approach the required minimum of 70%

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