REFEREED PAPER

MODIFIED 'TWIN-STACKER' CANE LOADING SYSTEM

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Abstract

The cost of hauling cane in the Zimbabwean sugarcane industry constitutes a substantial portion of production costs. On most farms and on large portions of the estates cane is cut and hand-piled into stacks weighing approximately five tons. These stacks are secured with two chains and loaded onto 'Perry' loaders for transport to a transloading site or direct to the mill. Muscane trailers have been used to improve the efficiency of the Perry loader operations. On some estates so-called 'Triple-stack' or 'Twin-stack' (T&TSLs) loaders are in use on some fields. However, it is difficult and time consuming to both chain and load a cane stack using the existing T&TSLs, and bundles are therefore pre-chained using a Perry loader in the field and then the T&TSLs loaders are used for transporting the bundles, two or three at a time, from the field edge to the transloading site. A new method to chain and load stacked cane using a Twin-stack loader has been developed. In this paper the new system is described and the costs and benefits of the new system relative to existing options are discussed. The new system was demonstrated and shown to work effectively. Proper implementation of the new system could result in a nearly three-fold increase in the productivity of tractors, drivers and chain-hands relative to Perry loaders, and very substantial cost reductions.

Keywords: sugarcane, harvesting, economics, twin-stack loader, Perry loader, cut and stack

Introduction

The cost of loading and transporting sugarcane constitutes a very substantial portion of sugar production costs (Gillitt, 2005). In the Zimbabwean sugar industry the majority of cane is cut and hand-piled into stacks weighing approximately five tons. These stacks are prepared for transport using two chains placed around the stack which are pulled tight so that the cane becomes tightly held together in a bundle. Most of the road trailers and railway carriages are designed to carry bundled cane rather than loose cane.

Side-load winching systems used to load cane stacks in South Africa are not well suited to Zimbabwe because the majority of cane is furrow irrigated. On furrow irrigated fields, cane is stacked by laying cane stalks at right angles to the direction of the furrows. This makes it possible to 'feed' chains under the stacks as shown in Figure 1. If side-loaders were used they would have to travel across the furrows to permit loading. This would be uncomfortable, inefficient and damaging to the field. If cane was laid and stacked parallel to the direction of the furrows, it would be extremely difficult to 'feed' the chains under the stack.

A small proportion of the furrow irrigated cane is mechanically loaded. While the use of mechanical loaders should result in gains in productivity, especially with regard to cane cutters, the layout of most furrow irrigated fields is such that the haul-out trailers associated with mechanical loaders often travel directly over cane stools. This can lead to serious compaction damage and declining cane yields (Tweddle *et al*., 2015). Systems to permit mechanical loading, while at the same time minimising compaction and feeder-canal

damage are being developed (for example, Lecler, 2016), however, it will likely be some time before any new developments are adopted throughout the industry.

At present, the implement most often used to chain cane stacks and transport the bundled cane to a transloading site or direct to the Mill is called a Perry loader, as shown in Figure 1. Muscane trailers have been used to improve the efficiency of the Perry loader operations. Typically, when Muscane trailers are used, a Perry loader will offload two bundles of cane into two Muscane trailers, and then the two Muscane trailers are towed behind a laden Perry loader to the Mill or transloading site, thus increasing the payload during transporting to approximately 15 tons. Muscane trailers cannot offload cane; therefore, there needs to be a functioning crane at the offload site if Muscane trailers are used. When a crane is not functioning there can be lengthy delays associated with the use of Muscane trailers.

Figure 1. Chaining and loading stacked cane with a Perry loader in a furrow irrigated field in Zimbabwe.

In addition to Perry loaders, estates also use so-called Triple-stack and Twin-stack loaders (T&TSLs). These can winch pre-chained cane bundles onto a trailer and offload the bundles without requiring any additional cranes, i.e. using only the hydraulic system of the towing tractor. There have been challenges using the T&TSLs to both chain and load bundles in-field. When this operation was observed, one of the major stumbling blocks was the procedure used to secure the chains around the bundle and winch it onto the trailer. The procedure observed was not very efficient or safe and it took more than 20 minutes to chain and load one bundle. An additional issue with the Triple-stack loader is its length. Because it is so long it is very difficult to manoeuvre a Triple-stack loader in the field. As a result of these loading challenges, T&TSLs are typically used together with Perry loaders; Perry loaders are used in-field to chain the cane stacks, and the Triple-stack or Twin-stack loaders are then used to transport the bundled cane, two or three bundles at a time, from the field edge to the offloading site.

A new system to chain and load cane which has been cut and stacked was developed. In this paper the new system to load bundles in-field using Twin-stack loaders is described. In a mainly desk-top analysis, the costs and productivity associated with the new system were compared to the following traditional loading and transport options:

- Perry loaders;
- Perry loaders with two Muscane trailers;
- Perry loaders used in-field with a Triple-stack trailer used to transport the bundles from the field edge to the offloading site.

Methodology

In order to compare loading and transport operations the Zimbabwe Sugar Association Experiment Station (ZSAES) farm was used as a representative case study. Distances from the ZSAES farm to the transloading site were assessed using the speedometer of a Ford Ranger truck, as were the typical transport speeds. The time taken to load a bundle of cane using a Perry loader was based on observations at the ZSAES and in the industry. The time and speed estimates used for the Triple-stack loader and the proposed new Twin-stack loading system were based on observations of the systems in use and associated discussions with the operators. The estimates used were considered sufficiently representative for determining the potential of the proposed new chaining and transport system, relative to traditional options.

Machinery costs were determined following reference to guidelines provided by the South African Institute of Agricultural Engineers, as described in Green *et al*. (1986). Details were as follows:

- interest costs were based on the average value of the machine at the relevant interest rate, i.e. (purchase price (less tyres) + salvage value)/2 x interest rate (%);
- an interest rate of 12% was assumed;
- depreciation was calculated using straight line depreciation, i.e. (cost – salvage value)/ (years owned);
- salvage value for tractors was 35% of purchase price after 5 years, with 5% added for each year less and 5% subtracted for each year more;
- salvage value for all the trailers was 10% after 10 years ±2% per year;
- repair and maintenance for the loaders was 50% of the purchase price and for tractors, 100% of the purchase price;
- tyre life for transport tractors and the loaders was taken as 1500 hours;
- fuel consumption was taken as 0.33 l/kWh assuming 80% of available power was used for loading and transport, 80% of the time.

Wage estimates used in the analysis were $14.58 per day for a chain-hand, $19.66 per day for a tractor driver and $21.75 per day for a driver of a Triple or Twin-stack loader. Costs of labour included estimates for various non-cash benefits such as housing, medical assistance, water, electricity and schooling, as applicable at the ZSAES.

Description of the novel in-field chaining and loading system

The new chaining and loading system is illustrated and explained in Figure 2.The new system involved welding pieces of slotted channel iron to the sides of the loader to act as chain locks and then making a stopper clip to prevent the hook mechanism on the chains from sliding during the early stages of loading (refer Figure 2). The new chaining and loading system can be used with both Triple- and Twin-stack loaders. However, since it is very difficult to manoeuvre Triple-stack loaders in fields and more efficient to load and haul two relatively larger bundles at a time, rather than three smaller bundles, the system is recommended for use with Twin-stack loaders.

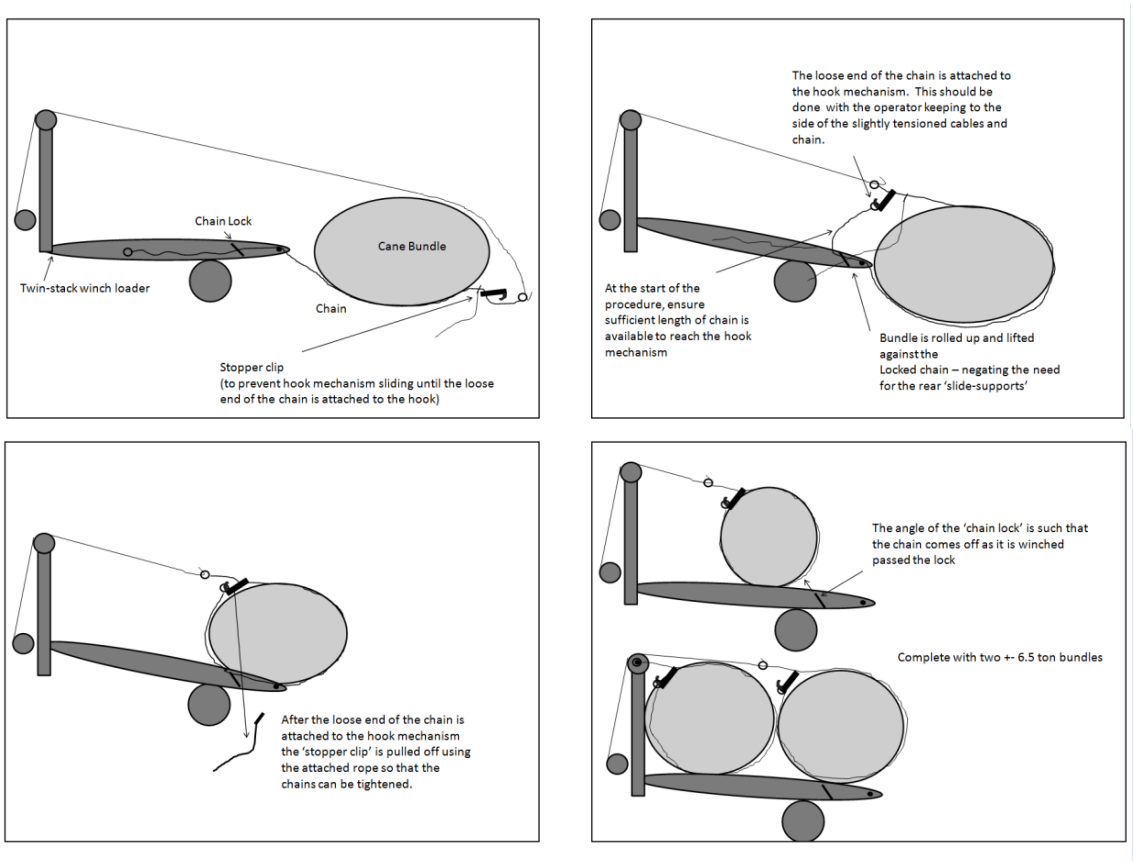

Figure 2. Schematics to illustrate the novel in-field rear loading and chaining system. The order of the procedure is from left to right and top to bottom – refer also to Figure 3.

Results

In order to test the new chaining and loading system, stopper clips were made to prevent the sliders moving in the early stages of the procedure and chain-locks were welded to a borrowed Triple-stack loader, which was then used to load a cane stack, as shown in Figure 3.

Figure 3. Initial testing of the new chaining and loading system.

Following the initial tests, the new chaining and loading system was successfully demonstrated to hundreds of farmers and estates personnel at a ZSAES Field Day on 17March 2016. At the Field Day a bundle was chained and loaded in less than six minutes even though it was a new procedure, i.e. relatively unrehearsed or practised.

Productivity estimates for the various loading and haulage options were calculated in terms of tons per tractor per day and also the time required to remove cane stacked on a five hectare field yielding 120 tons cane per hectare. Using relationships between speed, distance and travel time together with the typical loading and offloading times associated with the various options, the times to load and transport a bundle of cane were determined. The assumptions and calculations for the four different options considered are shown in Tables 1, 2 and 3.

Table 1. Common values used in the productivity calculations.

ZSAES Research Farm		
Main gate to Loading Zone	4.5	km
Average distance to main gate	0.69	km
Hectares harvested	5	ha
Average Yield	120	t/ha
Average trailer weight	5	t
No. Of bundles	120	
Waiting/Rest/Unproductive time	0.75	hrs
Shift time	8.75	
Working time per tractor shift	8	hrs

Table 2. Time to chain and load cane stacks: Perry loader and Perry loader plus Triple-stack loader.

Perry Loader	Avg Speed (km/h)	Time (min)
In-field manoeuvring	2	1.5
In-field loading of the bundle		12.5
Travel time to main gate	12	3.5
Travel time to zone from main gate	24	11.3
Off-load bundle		2.0
Collect chains		1.0
Return to main gate	24	11.3
Return to field	12	3.5
Total time for 1 (5t) bundle		46.4

	Perry Loader plus Triple-Stack Loader		
	Field to transfer zone - Perry loader	Avg Speed (km/h)	Time (min)
	In-field manoeuvring	2	1.5
	In-field loading of the bundle		12.5
	Travel time to transfer zone/edge of field road	5	1.8
	Off-load bundle		1
	Return to field	5	1.2
A		Total	18
	Transfer zone to transloading site - Triple stack trailer		
	Winch 3 bundles		9
	Travel to loading zone	24	12.1
	Offload/collect 3 bundles		5
	Travel back to transfer zone	24	12.1
B		Total	38.2
C	Waiting time	(3xA) - B	15.8
	Total time for 3 (5 t) bundles	B + C	54

Table 3. Time to chain and load cane stacks: Perry loader plus two Muscane trailers and Twin-stack loader using novel chaining and loading system.

Perry Loader plus 2 Muscane Trailers

	Field to transfer zone		Avg Speed (km/h)	Time (min)
A	In-field manoeuvring		2	1.5
B	In-field loading of the bundle			12.5
C	Travel time to transfer zone/edge of field road		15	3.0
	Off-load bundle			1.0
	Return to field		15	2.8
D			Total	20.7
	Transfer zone to loading zone			
	Hitch/unhitch	2 bundles/trailers		3.0
	Travel to loading zone		22	11.6
	Offload	3 bundles/trailers		6.0
	Travel back to transfer zone		24	10.6
E			Total	31.2
	Total time for 3 (5 t)	bundles 2xD+A+B+C+E		89.6

Twin-Stack Loader with Novel In-field Chaining and Loading System

	Avg Speed (km/h)	Time (min)
In-field manoeuvring	2	1.5
In-field loading of the 2 x bundles		12
Travel time to main gate	12	3.45
Travel time to zone from main gate	24	10.625
Off-load bundles		2
Collect chains		2
Return to main gate	24	10.625
Return to field	12	3.45
Total time for 2 (6.5t) bundles		44.15

A summary of the results from the productivity analysis using the times estimated in Tables 1,2and 3 is shown in Table 4. Tractor productivity was calculated by rounding up or down the bundles per shift calculation. For example, if the bundles per shift calculation resulted in 10.9 bundles, it was rounded up to 11 bundles per day to estimate tractor productivity.

Table 4. Productivity comparisons for different haulage options.

Equipment	Time to clear field - 5 ha @120t/ha (days)	Tractor productivity (t/tractor/day)
1 x Perry loader	12	50
1 x Perry loader + 2 x Muscane trailers	7.5	80
1 x Perry loader + 1 x Triple-stack trailer	4.4	67.5
1 x Twin-stack trailer with novel chaining system	4.2	143

Estimates of overhead, fuel, repairs and maintenance (R&M), labour and overall costs per ton of cane loaded and transported are shown in Figure 5,assuming the units were fully utilised, and Figure 6, assuming they are self-owned and used by growers with small farms.

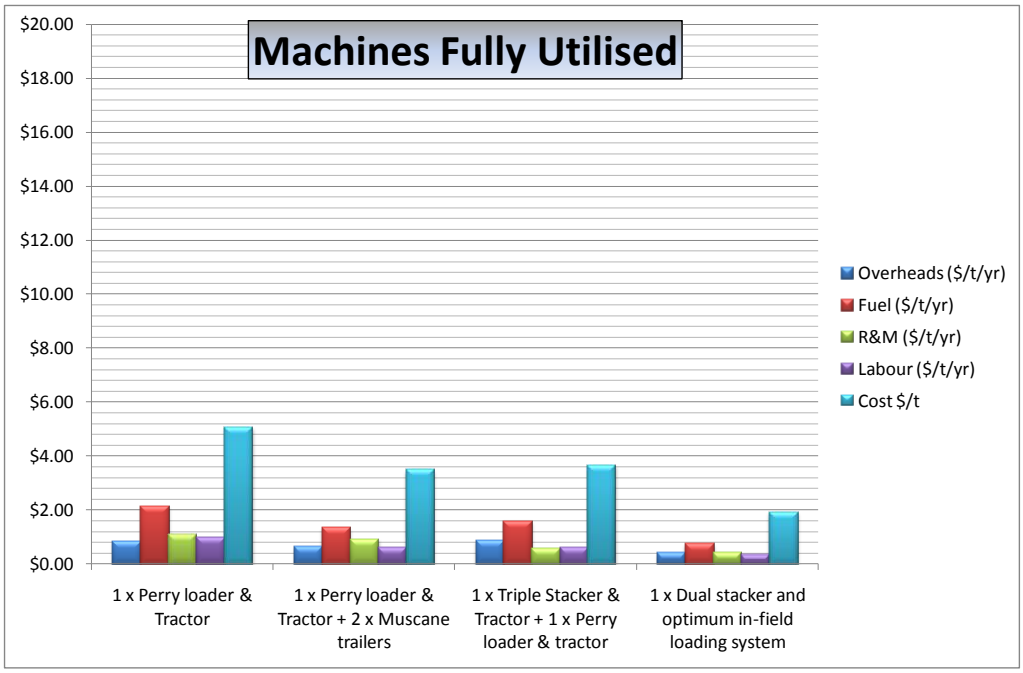

Figure 5. Comparative costs of the various loading and hauling options assuming the equipment was well utilised, as for example, should be the case on a large estate.

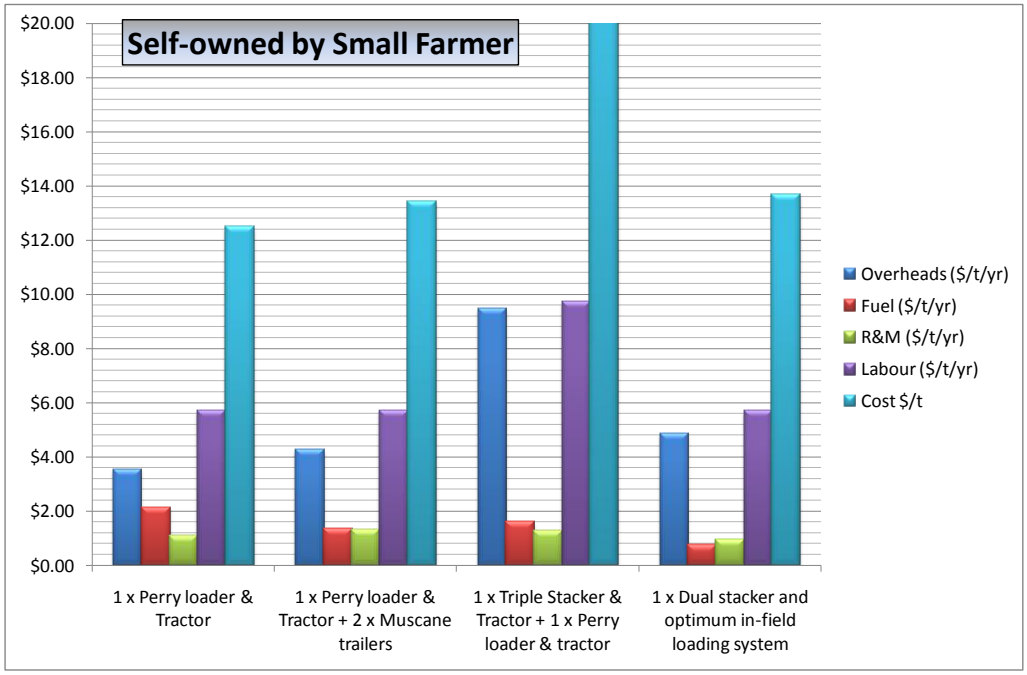

Figure 6. Comparative costs of the various loading and hauling options if the equipment is self-owned by a farmer with only a 20 hectare farm as is typical in the Zimbabwean sugarcane industry since the Government appropriated land.

Costs per ton shown in Figures 5 and 6 were based on machine costs shown in Appendix A; the productivity analysis shown in Table 4 and assuming 26 working days per month and a nine month milling season. Summary results from the costing exercise, which includes savings per ton cane loaded and transported if the various traditional systems are replaced with the new Twin-stack in-field chaining and loading system, are shown in Table 5.

Table 5. Summary results from the costing exercise. Savings are if the various fully utilised systems are replaced with the new Twin-stack loading system.

Equipment set	Potential productivity (t/season)	Productivity on 20 ha farm @ 100t/ha	Cost if machines fully utilised ($/t)	Cost if machines only used on small farm ($/t)	Saving If replaced ($/t)
1 x Perry loader & Tractor	11700	2000	$5.06	$12.49	$3.13
1 x Perry loader & Tractor + 2 x Muscane trailers	18720	2000	$3.50	$13.43	$1.57
1 x Triple- stack loader & Tractor + 1 x Perry loader & Tractor	31590	2000	$3.63	$24.72	$1.70
1 xTwin-Stack loader using novel in-field chaining & loading system	33462	2000	$1.93	$13.70	$0.00

Discussion and Conclusions

A new chaining and loading system which permits the in-field loading of cane stacks on typical furrow irrigated field layouts was developed and demonstrated at a ZSAES Field Day. The new system could result in a nearly three-fold increase in the productivity of tractors, drivers and chain-hands compared to when Perry loaders are used. For fully utilised machines the new system could result in estimated savings ranging from $1.57, if Perry loaders and Muscane trailers are replaced with the new system, to $3.13, if Perry loaders are replaced with the new system, per ton cane harvested per year. On the estates in Zimbabwe where more than 20000 hectares of sugarcane are cut and stacked, the potential savings are likely to exceed$5.5 million per year if the new system were to be further developed and properly implemented. There is room to improve the design of the winching mechanism used on existing Twin-stack loaders.

Many small farmers have their own tractors and Perry loaders. On a small farm, there is not enough sugarcane to use these machines to their full potential. As a result, the cost per ton loaded and transported was estimated to be relatively high compared to when the machines are fully utilised, even taking the extended lifespan of machines into account. If a small farmer could hire a Twin-stack loader at a realistic rate, rather than use his own Perry loader, savings in the region of $10 per ton cane harvested per year should be possible, i.e. savings in the region of $18 000 per farmer. Using Perry loaders to chain stacks and transport these to the Mill or transloading site, although popular, is a relatively expensive loading and transport option. In this costing exercise it has been assumed that, in order to achieve a rateable supply of cane to the Mill, drivers and chain-hands would have to be hired continually for the duration of the milling season, i.e. not for only one or two days every month. As a result, the cost of labour for a small farmer using his or her own machinery is relatively large. Alternatively, a small farmer would face the challenge of re-engaging suitable drivers and chain-hands every month or finding alternative work for them so that their costs can be assigned elsewhere.

Equipment costs, especially overheads, should be spread over as many tons of cane as possible. Even on estates where machines are better utilised due to the relatively large areas of sugarcane, having workers work in shifts, where possible, should dilute the overhead costs of expensive equipment and result in savings. Asking drivers and chain-hands to work overtime is not advised as this may lead to accidents related to fatigue.

If the number of machines transporting cane is excessive, as will be the case if each small farm has their own tractor and Perry loader, it is likely that there will be excessive queuing and unproductive time at the offloading sites and a longer burn to crush delay leading to increased sucrose losses. The industry should, therefore, in addition to adopting the new Twin-stack chaining and transport system, work together to co-ordinate harvesting fronts and optimise the use of equipment so that queuing is minimised. Ideally, owners of small farms need to be able to hire equipment through a reliable and low cost service provider in a well co-ordinated system.

Where cane is burnt prior to cutting, the area burnt needs to be closely matched to machine productivity, otherwise there will be excessive burn to crush delays and associated sucrose losses. For example, in the ZSAES case study, if a typical five hectare field was burnt at once it would take 12 days to load and transport all the resultant cane stacks using one Perry loader. Thus, if Perry loaders are used, their relatively low productivity would mean that only relatively small portions of a field should be burnt at a time and this will add additional challenges to the harvesting process.

Ultimately the implementation of systems, for example, the controlled traffic farming and synergetic surface irrigation system reported by Lecler (2016), which permit mechanical loading whilst at the same time minimising compaction damage and damage to field infrastructure are likely to lead to the lowest harvesting, loading and transporting costs. For small farms to benefit they will need to hire appropriate equipment or services from a suitable service provider and have organisational structures to permit relatively large areas to be harvested at a time.

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Appendix A: Cost estimates

Two scenarios were assumed, one where the equipment is owned and used on a typical small farm and one where the equipment is fully utilised, as for example it should be on an estate.

	Haulage Tractor (	80	Hp	
			20 Ha farm @100t/ha	Fully Utilised
	Life (h)	12000		
	R&M over life	100%		
	Annual Use (hr)		320	1872
	Life in Years		15.0	6.4
Total Investment		$35,000.00		
Deduct tyre value			$3,400.00	$3,400.00
Deduct Salvage Value			$1,750.00	$9,782.05
Amount to be depreciated			$29,850.00	$21,817.95
FIXED COSTS				
Depreciation			$1,990.00	$3,403.60
Shelter (with lic and ins)				
License and Insurance			$700.00	$700.00
Interest	12%		$2,205.00	$2,686.92
Total Annual Fixed Costs			$4,895.00	$6,790.52
OPERATING COSTS				
Fraction available power			0.80	0.80
Fuel ($/l)				
	l/h		12.6	12.6
	$		$4,275.42	$25,011.19
Lubrication (with R&M)				
R&M			$933.33	$5,460.00
Tyres			$725.33	$4,243.20
Operator			$4,600.44	$4,600.44
Total Annual Operating Costs			$10,534.52	$39,314.83
Total Annual Cost			$15,429.52	$46,105.36
Total Cost per Hour			$48.22	$24.63

	Perry Loader			
			20 Ha farm @100t/ha	Fully Utilised
	Life (h)	12000		
	R&M over life	50%		
	Annual Use (hr)		320	1872
	Life in Years		15.0	6.4
Total Investment		$15,800.00		
Deduct tyre value			$1,400.00	$1,400.00
Deduct Salvage Value			$790.00	$2,714.36
Amount to be depreciated			$13,610.00	$11,685.64
FIXED COSTS				
Depreciation			$907.33	$1,822.96
Shelter (with lic and ins)				
License and Insurance			$316.00	$316.00
Interest	12%		$995.40	$1,110.86
Total Annual Fixed Costs			$2,218.73	$3,249.82
OPERATING COSTS				
Fraction available power			0.00	0.00
Fuel ($/l)				
	l/h		0.0	0.0
	$		$0.00	$0.00
Lubrication (with R&M)				
R&M			$210.67	$1,232.40
Tyres			$298.67	$1,747.20
Operator (2 chainhands)			$6,822.00	$6,822.00
Total Annual Operating Costs			$7,331.33	$9,801.60
Total Annual Cost			$9,550.07	$13,051.42
Total Cost per Hour			$29.84	$6.97

	Muscane trailer		20 Ha farm @100t/ha	Fully Utilised
	Life (h)	12000		
	R&M over life	50%		
	Annual Use (hr)		200	1872
	Life in Years		15.0	6.4
Total Investment		$5,500.00		
Deduct tyre value			$1,400.00	$1,400.00
Deduct Salvage Value			$275.00	$944.87
Amount to be depreciated			$3,825.00	$3,155.13
FIXED COSTS				
Depreciation			$255.00	$492.20
Shelter (with lic and ins)				
License and Insurance			$110.00	$110.00
Interest	12%		$346.50	$386.69
Total Annual Fixed Costs			$711.50	$988.89
OPERATING COSTS				
Fraction available power			0.00	0.00
Fuel ($/l)				
	l/h		0.0	0.0
	$		$0.00	$0.00
Lubrication (with R&M)				
R&M			$45.83	$429.00
Tyres			$186.67	$1,747.20
Operator			$0.00	$0.00
Total Annual Operating Costs			$232.50	$2,176.20
Total Annual Cost			$944.00	$3,165.09
Total Cost per Hour			$4.72	$1.69

	Twin Stacker		20 Ha farm @100t/ha	Fully Utilised
	Life (h)	12000		
	R&M over life	50%		
	Annual Use (hr)		112	1872
	Life in Years		15.0	6.4
Total Investment		$34,000.00		
Deduct tyre value			$1,400.00	$1,400.00
Deduct Salvage Value			$1,700.00	$5,841.03
Amount to be depreciated			$30,900.00	$26,758.97
FIXED COSTS				
Depreciation			$2,060.00	$4,174.40
Shelter (with lic and ins)				
License and Insurance			$680.00	$680.00
Interest	12%		$2,142.00	$2,390.46
Total Annual Fixed Costs			$4,882.00	$7,244.86
OPERATING COSTS				
Fraction available power			0.00	0.00
Fuel ($/l)				
	l/h		0.0	0.0
	$		$0.00	$0.00
Lubrication (with R&M)				
R&M			$158.67	$2,652.00
Tyres			$104.53	$1,747.20
Operator (2 chain-hands)			$6,822.00	$6,822.00
Total Annual Operating Costs			$7,085.20	$11,221.20
Total Annual Cost			$11,967.20	$18,466.06
Total Cost per Hour			$106.85	$9.86

	Triple Stacker		20 Ha farm @100t/ha	Fully Utilised
	Life (h)	12000		
	R&M over life	50%		
	Annual Use (hr)		119	1872
	Life in Years		15.0	6.4
Total Investment		$48,000.00		
Deduct tyre value			$1,400.00	$1,400.00
Deduct Salvage Value			$2,400.00	$8,246.15
Amount to be depreciated			$44,200.00	$38,353.85
FIXED COSTS				
Depreciation			$2,946.67	$5,983.20
Shelter (with lic and ins)				
License and Insurance			$960.00	$960.00
Interest	12%		$3,024.00	$3,374.77
Total Annual Fixed Costs			$6,930.67	$10,317.97
OPERATING COSTS				
Fraction available power			0.00	0.00
Fuel ($/l)				
	l/h		0.0	0.0
	$		$0.00	$0.00
Lubrication (with R&M)				
R&M			$238.00	$3,744.00
Tyres			$111.07	$1,747.20
Operator (1 chain-hand)			$3,411.00	$3,411.00
Total Annual Operating Costs			$3,760.07	$8,902.20
Total Annual Cost			$10,690.73	$19,220.17
Total Cost per Hour			$89.84	$10.27