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THE COST OF SILAGE HARVEST AND TRANSPORT SYSTEMS FOR HERBACEOUS CROPS

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ABSTRACT

Some of the highest yielding herbaceous biomass crops are thick-stemmed species such as energy cane (Saccharum ssp.), Napiergrass (Pennisetum purpureum), and forage sorghum (Sorghum bicolor). Their relatively high moisture content necessitates they be handled and stored as silage rather than hay bales or modules.

This paper presents estimated costs of harvesting and transporting herbaceous crops as silage. Costs are based on an engineering-economic approach. Equipment costs are estimated by combining per hour costs with the hours required to complete the operation. Harvest includes severing, chopping, and blowing stalks into a wagon or truck.

For 50% moisture content, in-field costs using trucks in the field (options 0 and 1) are $3.72 to $5.99/dry Mg ($3.37 to $5.43/dt) for a farmer and $3.09 to $3.64/dry Mg ($2.81 to $3.30/dt) for custom operators. However, slopes and wet field conditions may not permit trucks to enter the field. Direct-cut harvest systems using wagons to haul silage to trucks waiting at the field edge (option 2) are $8.52 to $11.94/dry Mg ($7.73 to $10.83/dt) for farmers and $7.20 to $7.36/dry Mg ($6.53 to $6.68/dt) for custom operators. Based on 4 round trips per 8-hour day, 50 and 70% moisture silage, truck transport costs are $8.37/dry Mg ($ 7.60/dt) and $13.98/dry Mg ($12.68/dt), respectively. Lower yields, lower hours of machine use, or a higher discount rate result in higher costs.

Keywords: cost, economics, herbaceous, biomass, silage, harvest, transport

INTRODUCTION

There are two types of forages: thin-stemmed (e.g. switchgrass) and thick-stemmed (e.g. sweet sorghum, energy cane). Thin-stemmed species can be handled as silage (60%-70% moisture), haylage (40%-50% moisture), or hay (10%-20% moisture). Thick-stemmed species can be handled as silage or haylage. The handling systems considered for silage

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and haylage are the same, and henceforth we will call both systems silage.

The objective of this paper is to cost appropriate machinery complements for silage operations. The complements vary by farm size and for a custom harvest operation. Capital costs range widely. For example, a pull-type forage harvester can cost as little as $14,000, while a self-propelled (SP) forage harvester can cost as much as $170,000, with many options in between. There is a tradeoff between capital cost of equipment and labor requirements. To effectively use the more expensive equipment either a very large farm or a custom operation is required. More detailed information can be found in Turhollow et al (1996).

Two methods are available for handling high moisture crops: 1) a direct-cut system and 2) a wilting (a cut, wilting in the fields, and pickup) system. If moisture content of the crop at harvest is below 75%, the direct-cut system can be used, otherwise it is necessary to reduce the crop's moisture content by letting it wilt in the field from 2 hours to 2 days, which reduces the moisture content to 40 to 50%. In general it is preferable to use the direct-cut system because less operations are involved and handling losses are lower. Four options for direct-cut silage are considered. All use a forage harvester to cut the crop. In option 0 the crop is then blown directly into a truck in the field. In option 1 the crop is blown into a wagon pulled by the forage harvester, then dumped into a truck in the field. In option 2 the crop is blown into a wagon pulled by the forage harvester, then dumped into a tractor-pulled forage wagon, and then dumped into a truck at the field edge. In option 3 the crop is blown into a wagon pulled by the forage harvester and unhitched when full and replaced by an empty wagon. The full wagon is then hitched to a tractor and hauled to the field edge and dumped into a truck. We cost options 0, 1, and 2.

The direct-cut system requires a forage harvester to blow the cut material into a forage wagon or truck. The length of the chopped material can be controlled by changing the knife configuration on the forage harvester. Forage harvesters can either be tractor pulled (pull-type) operating off the tractor's power takeoff (PTO) or self-propelled. One advantage of a self-propelled over a pull-type is that cutting takes place in front of the machine, not behind. We assume a small farmer doing his own harvesting would use a pull-type forage harvester while a very large farmer or custom operator would use a self-propelled forage harvester. This decision is based upon costs.

IN-FIELD TRANSPORTATION

Silage can be transported by truck, a combination of trucks and wagons, or wagons. The silage or haylage systems under consideration handle large volumes and masses. Fresh-cut silage is 426 kg/m^3 (26 lb/ft^3) (Rider et al 1993). Assuming fresh-cut silage is at 70% moisture, then density is 125 dry kg/m^3 (7.8 dry lb/ft^3). The thick-stemmed energy crops considered for handling as silage or haylage will be more mature at harvest than typical corn silage, so we assume it is 50% moisture, and its density is 250 kg/m^3 (15.6 lb/ft^3). Based on 22.4 dry Mg/ha [10 dry tons (dt/ac)], at 70% field efficiency a 2-row pull-type forage harvester handles 112 m^3 (3300 ft^3) or 28 Mg (25.4 tons)/hr and a 6-row self-propelled forage harvester handles 320 m^3 (11,400 ft^3) or 80.7 Mg (89.0 tons) of biomass/hr.

To reach the legal load weight limit, which minimizes transportation costs, the truck transporting the biomass to the conversion facility requires approximately a 14.7 m (48') long, 3.5 m (11.4') tall, and 2.6 m (8.5') wide; or 11.3 m (37') long, 4.3 m (14') tall, and 2.6 m (8.5') wide truck trailer.

Blowing directly into a truck (option 0) appears to be the least cost method, by minimizing the amount of equipment required, the number of operations, and maximizing active forage harvesting time. Disadvantages of this system are: the truck driver has to constantly keep up with the forage harvester, not all field conditions (e.g. wetness and slope) are suitable for the truck, the 4.3 m (14') tall truck is too high for forage harvesters to blow into, losses are higher blowing into a truck without a roof as opposed to a forage wagon with a roof, and the exact weight of the biomass blown into the truck is unknown, making it possible to go over the legal weight limit.

For option 1, even though dumping time is a relatively short 1 to 2.5 minutes, because of the large volumes of biomass handled, a high capacity wagon is desired. Wagons with roofs have capacities up to 31.2 m^3 (1100 ft^3) and wagons without roofs up to 25.5 m^3 (900 ft^3). Given that the truck transporting the silage to the conversion facility can transport a 22.7 Mg (25 ton) [91 m^3 (3200 ft^3)] load, then 3 wagon loads of 30.3 m^3 (1068 ft^3) or 7.56 Mg (8.33 tons) each [based on 250 kg/m^3 (15.6 lb/ft^3)] or 4 loads of 22.7 m^3 (800 ft^3) are required to fill the truck. We assume a forage harvester-pulled wagon has a scale, to ensure a truck is not overloaded, and it costs $3495. Standard dumping height for a high dump forage wagon is about 3.4 m (11') and with risers about 3.5 m (11.4'). If the truck trailer is 4.3 m (14') high then an extra high dumping wagon is needed.

For option 2 the tractor-pulled wagon has no a roof. The largest high dump wagon without a roof we know of is 25.5 m^3 (900 ft^3), can dump over 4.3 m (14') high, but has a 2.5 minute dump cycle. It is possible to haul a smaller and/or less expensive wagon behind the forage harvester. If dumping from one forage wagon to another, a 4.3 m (14') high dumping clearance is not required, but the standard 3.4 m (11') dumping clearance is adequate. The Miller Pro Model 4012, capacity of 22.7 m^3 (800 ft^3) and 8.2 Mg (9 tons) and dump cycle of 1 minute is an example. The disadvantage of this wagon is that the dumping height limits the height of a truck one can dump into, if one wants to sometimes use a higher than 3.5 m (11.4') trailer. For option 2 we cost 22.7 m^3 (800 ft^3) wagons.

For option 3, for a forage harvester with a 2-row head, hitching and unhitching would be acceptable from a time perspective, but for a self-propelled harvester with a 6-row head this would result in too much downtime for the expensive forage harvester and reduce field efficiency to about 50%.

For option 2, tractor-pulled forage wagon, total round trip time is 15.5 minutes; 9 minutes for travel, 2.5 minutes to be dumped into by the forage harvester hauled wagon, 2.5 minute to dump into a truck, and 3 minutes of slack time. Thus each wagon makes 3.87 round trips/hr. A 22.7 m^3 (800 ft^3) wagon carrying 5.66 Mg (6.24 tons) or 2.83 dry Mg (3.12 dt) has a capacity of 21.9 Mg (24.2 tons) or 11.0 dry Mg (12.1 dt)/hr.

The number of forage wagons required to transport silage from the field to the field edge depends on crop yield and moisture content, the forage crop head used, and its associated rate of operation (ha/hr or ac/hr), and the hourly capacity of each wagon. Four different row heads are considered (2 row, 3 row, 4 row, and 6 row). Based on 22.4 dry Mg/ha (10 dt/ac), for 22.7 m^3 (800 ft^3) wagons, a 2-row head requires 2 wagons, a 3-row head requires 2 wagons, a 4-row head requires 3 wagons [note that the 4-row head on a 201 kW (270 hp) forage harvester is limited to 21.7 Mg/ha (9.7 dt/ac) or a slower field speed by its power], and a 6-row head requires 4 wagons.

COSTS

Costs can be broken into the following categories:

- depreciation (or capital replacement)
- interest
- insurance, housing, and taxes
- repair
- fuel, lube, and oil
- labor

The ASAE (1995) has formulas to determine values of farm equipment after n years. The value as a percent of initial list price is $68(0.920)^n$ for tractors; $64(0.885)^n$ for combines, cotton pickers, and SP windrowers; $56(0.885)^n$ for balers, forage harvesters, blowers, and SP sprayers; and $60(0.885)^n$ for all others. Equipment is used for a certain number of years, based on assumed hours of life divided by hours of use.

Depreciation on a straight-line basis is:

depreciation/hr = (purchase price - discounted salvage value)/hrs of life

where purchase price is 90% of initial list price. We use a real interest rate of 6% (or in nominal terms about 9%). The average amount of interest paid in a year is:

interest = [(purchase price - discounted salvage value)/2]*interest rate

ASAE (1995) provides values for total lifetime undiscounted repair costs. Lifetime undiscounted repair costs are divided by number of hours of life to get repairs cost per hour. Insurance, housing, and taxes are 2% of list price.

From ASAE D497.2MAR94 and assuming X = 0.5 (Walsh 1995), typical diesel fuel consumption is:

L = maximum PTO power (kW) * 0.252
or gal = maximum PTO power (hp) * 0.04938.

Oil and lube costs are 15% of fuel costs. Diesel cost for off-road use (i.e. farm equipment) is assumed to be $0.211/L ($0.80/gallon) and for trucks is $0.304/L ($1.15/gallon). The difference is road use taxes.

For field labor, the number of labor hours required is 1.25 times the number of machine hours required. This allows for time spent transporting and setting up machinery. Labor is charged at $8/hr, including benefits, for agricultural operations (or $10/hr of actual equipment operation) and $15/hr for trucking, including benefits.

Area covered is determined from data in ASAE (1995) on equipment speeds, widths, and field efficiencies.

Truck and over-the-road transportation costs

Fuller et al (1992) list the price of a tandem truck of $46,000, annual use of 500 hrs, a lifetime of 5000 hrs, repair costs of $2.30/hr, and diesel use of 17.8 L/hr (4.7 gallons/hr). The price of truck listed is a net cost, so any dealer discounting is included. To adjust for inflation between 1992 and 1995 and for dealer discounting we assume a 1995 list price of $58,000 and to adjust for inflation, repair costs of $2.53/hr.

A silage truck is assumed to have a list price of $80,000, a lifetime of 5000 hrs, and operates 400 hrs/year. The 400 operating hrs/year is based on a custom silage operation working 400 hrs/year and the trucks that haul silage are used in a just-in-time manner (i.e. they haul silage when silage is being harvested) with no off-site (from the conversion facility) storage. Fuel use is the same as for the tandem truck. Repair costs are proportional to relative list prices of the silage and tandem truck, $3.49/hr ($80,000/$58,000*$2.53/hr). A silage truck operates 8 hours in an 8-hour working day and makes four round trips in a working day. Total cost including labor is $47.48/hr or $380/8-hr working day. Silage transport costs $8.37/dry Mg ($7.60/dt) for 50% dry matter content (baseline case) and $13.98/dry Mg ($12.68/dt) for 30% dry matter content (Table 1).

Table 1. Silage transport costs

capa-city	capa-city	density	density	mass/ trip	weight /trip	dry fraction	mass/ trip	weight /trip	cost	trips/ day	cost/ trip	cost	
m^3	ft^3	kg/m^3	lb/ft^3	Mg	ton		dry Mg	dt	$/8 hr day		$	$/dry Mg	$/dt
54	1920	416	26.0	22.6	25.0	0.3	6.8	7.5	380	4	95	13.98	12.68
94	3205	250	15.6	22.7	25.0	0.5	11.3	12.5	380	4	95	8.37	7.60

Tractor costs

Four tractor sizes are costed (including labor cost)(Table 2). Tractors are used with all field equipment except those that are self propelled and heads on self-propelled equipment.

Table 2. Tractor costs

power		life		annual use	list price	total cost
kW	hp	hr	years	hr	$	$/hr
33.6	45	12000	24	500	21000	17.25
74.6	100	12000	21.82	550	42000	24.59
119.4	160	12000	20	600	72000	33.97
156.7	210	12000	20	600	93000	41.12

Sources: ASAE (1995), NAEDA (1995)

Silage costs

The first machines used for direct-cut silage systems are pull-type or self-propelled forage harvesters. We calculate costs for two pull-type: a forage harvester with a 2-row head powered by a 119 kW (160 hp) tractor and a forage harvester with a 3-row head powered by a 157 kW (210 hp) tractor (Table 3). These are heavy-duty pull-type forage harvesters. We also calculate costs for two self-propelled forage harvesters: a 201 kW (270 hp) model with a 4-row head and a 321 kW (430 hp) model with a six-row head (Table 32). All four configurations are capable of handling 22.4 dry Mg/ha (10 dt/ac) yields except the 201 kW (270 hp) self-propelled model, which is limited to 21.8 dry Mg/ha (9.7 dt/ac) or a slower approach field speed by its available power at the assumed cut length of 9 mm (0.35"). At a longer cut length the 201 kW (270 hp) self-propelled model could handle 22.4 dry Mg/ha (10 dt/ac). Based on average field speeds from ASAE (1995), the coverage of the forage harvesters is controlled by the head size and the assumed 76 cm (30") row width. Forage harvesters are expensive to operate, costing between $55 and $121/hr and $67 to $106/ha ($27 to $43/acre) (including labor) at 70% field efficiency.

High dump forage wagons are used in all options except option 0. If the wagon is pulled behind a forage harvester it is assumed to have both a roof and scale. If silage is dumped from the harvester-pulled wagon into a tractor-pulled wagon the tractor-pulled wagon has no scale and no roof. Using high volume wagons. 22.7 and 31.1 m^3 (800 and 1100 ft^3), these wagons cost between $14.39 and $17.55/hr (Table 4). If they are hauled by a 34 kW (45 hp) tractor, the tractor costs an additional $17.25/hr (including labor).

Table 3. Forage harvester costs.

implement	power		life		annual use	list price	total cost	area covered		total cost	
	kW	hp	hr	yr	hr	$	$/hr	ha/hr	ac/hr	$/ha	$/ac
forage harvester	119.4	160	2500	10	250	22000	17.03			33.05	13.38
2-row head	119.4	160	2000	10	200	3600	3.75	0.52	1.27	7.29	2.95
tractor	119.4	160	12000	20	600	72000	33.97			65.93	26.69
total						97600	54.76			106.27	43.02
forage harvester	156.7	210	2500	10	250	22000	17.03			22.04	8.92
3-row head	156.7	210	2000	10	200	6000	6.26	0.77	1.91	8.09	3.28
tractor	156.7	210	12000	20	600	93000	41.12			53.20	21.54
total						121000	64.40			83.33	33.74
SP forage harvester	201.4	270	4000	10	400	116000	74.05			61.59	24.93
4-row head	201.4	270	2000	5	400	10000	8.66	1.20	2.97	7.20	2.92
total						126000	82.70			68.79	27.85
SP forage harvester	320.8	430	4000	10	400	168000	104.53			57.96	23.46
6-row head	320.8	430	2000	5	400	19000	16.45	1.80	4.45	9.12	3.69
total						187000	120.98			67.08	27.16

Sources: ASAE (1995), NAEDA (1995)

[a] at 70% field efficiency

Table 4. Costs for high dump forage wagons used for silage

implement	capacity		life		annual use	list price	total cost
	'm³'	'ft³'	hr	years	hr	$	$/hr
scale, risers, dump clearance 3.47 m (11.4'), roof	22.7	800	2000	10	200	16160	14.39
no scale, dump clearance 4.57 m (15'), no roof	22.7	800	2000	10	200	19200	17.10
scale, risers, dump clearance 3.47 m (11.4'), roof	31.2	1100	2000	10	200	19710	17.55

Sources: ASAE (1995), Miller-St. Nazianz (1995), NAEDA (1995)

In-field production costs for options 1 and 2 based on 50% moisture content are shown in Table 5. They range from $3.09 to $11.94/dry Mg ($2.81 to $10.83/dt). Silage transport costs add $8.37/dry Mg ($7.60/dt).

Table 5. In-field production costs for options 1 and 2 based on 50% moisture content

	option 0	option 1	option 2	option 0	option 1	option 2
	$/dry Mg			$/dt		
pull-type (farmer)						
2-row head	4.74	5.99	11.94	4.30	5.43	10.83
3-row head	3.72	4.55	8.52	3.37	4.13	7.73
self-propelled (custom operator)						
4-row head	3.16	3.64	7.36	2.87	3.30	6.68
6-row head	3.09	3.48	7.20	2.81	3.16	6.53

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