FEASIBILITY OF DIRECT-CUT FORAGE CONSERVATION IN QUEBEC

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Mathematical models were used to simulate alfalfa growth, forage harvest, field drying and losses, storage handling and losses, and feeding to a dairy herd, including estimates of feed supplements required. Direct-cut alfalfa, at 80% moisture and preserved with formic acid, was compared with alfalfa wilted to 50% moisture. Each system was simulated over a 10-yr period (1967–1976) with climatic data from Quebec City. Direct-cut alfalfa had about 9% less field losses, a higher feeding quality and less variation in annual feed costs than wilted alfalfa. However, the average cost for both systems was about the same because of the substantial cost of formic acid. The current break-even point is a treatment cost not exceeding \$4.50/ton of wet alfalfa. The potential for direct-cut conservation may be enhanced with lower cost storage structures. Direct-cut conservation may also be more economical in areas where grasses are the main forage because they require less acid than legumes.

Des modèles mathématiques ont permis de simuler la croissance de la luzerne, les chantiers de récolte, le séchage et les pertes au champ, la manutention et la perte en entrepôt, et enfin l'alimentation à un troupeau laitier, avec calcul des suppléments requis. On a comparé la coupe directe de la luzerne, à une teneur en eau de 80% et conservée avec de l'acide formique, avec de l'ensilage de luzerne préfanée à une teneur en eau de 50%. Des données climatiques de la ville de Québec (1967–1976) ont servi à simuler les deux systèmes sur une période de 10 ans. La coupe directe a permis de réduire les pertes au champ de 9%, et d'obtenir une meilleure qualité et des coûts annuels de suppléments moins variables qu'avec l'ensilage préfané. Cependant le coût moyen des deux systèmes était sensiblement le même en raison du coût élevé de l'acide formique, dont le seuil de rentabilité se situe présentement à un coût d'application de 4,50\$ par tonne de luzerne humide. Le système de coupe directe peut devenir plus favorable par une réduction des coûts d'entreposage. La coupe directe sera encore plus attrayante dans les régions à prédominance de graminées fourragères qui nécessitent moins d'acide que les légumineuses.

INTRODUCTION

Dry matter and nutritive losses during forage harvest and storage can be considerable. Several researchers have estimated field losses due to mechanical fragmentation, cellular respiration and weathering to be on the average 5–6% per day of curing for alfalfa, and 3–4% per day for grasses (Shepherd et al. 1954; Cabon 1982; Rees 1982). Storage losses can be as high as 10–20% especially with wet silage or with hay stored outside (Kjelgaard 1979). In addition to quantitative losses, there are generally some qualitative losses in the form of reduced protein and energy concentrations. Indeed most of the material losses are from the nutrient-rich parts of the crop, namely leaves and soluble nutrients which are leached from the stems and from the leaves.

A reduction of these losses would mean that less land is needed to produce the same amount of forage and less supplements are purchased to balance rations for ruminants. As long as the cost of land and the cost of supplements (especially corn and soybean meal) are low, there is little incentive to improve forage conservation. In the long run though, we might expect land and feed prices to increase substantially; such circumstances would justify the conservation of a greater quantity of higher quality forage per unit area.

The most effective way to reduce forage field losses is by direct-cut without any field curing. The main problem then is to avoid seepage losses and unfavorable fermentation which are characterisic of wet silage. Two techniques have been proposed to deal with this problem: addition of an organic acid to enhance lactic fermentation, or fractionation of the wet crop into a mechanically pressed silage similar to wilted silage and a liquid fraction rich in soluble protein (Bruhn and Koegel 1977). Only the first technique, formic acid treatment, will be considered in the present paper as it might apply to alfalfa production under Quebec climatic conditions.

Among the large number of additives which have been tried and promoted, formic acid has stood out as one of the best and most predictable, especially for very wet silage (Thomas 1978). It is recommended at a level of 2–3 L/ton of wet grass, and 4–6 L/ton of wet legume (McDonald 1981). Formic acid decreases the pH to a low enough level, around 4.5, that only lactic acid bacteria still remain active and produce an excellent fermented silage.

The objective of the present study was to consider the physical and economical feasibility of direct-cut silage conservation for Quebec, by comparing it with wilted silage. Comparisons were based on resources required for each system, the expected cost and the year-to-year variation in cost due to weather change.

METHODOLOGY

Mathematical models were developed to simulate alfalfa growth, harvest, storage and feeding to dairy cows. The basic components are described in Savoie et al. (1985).

The alfalfa growth model was based on a physiological yield model developed by Fick (1977) and modified by Parsch (1982) to include quality parameters. Daily yields and changes in crude protein, total digestible nutrients and crude fiber were estimated as a function of a soil-water budget, available solar radiation and air temperture. The harvest model, developed by Savoie (1982), included daily decisions with regard to mowing, raking and harvesting; it predicted daily field losses due to mechanical fragmentation, respiration and weathering; it also predicted the drying rate each day and the time when windrows could be harvested.

The forage was stored either in a single silo, or in two silos with a distinction between high and low quality forage. Losses in storage were estimated once a year based on average data from Kjelgaard (1979) and McIsaac and Lovering (1980). The feeding model allocated higher quality forages to higher producing cows, and lower quality forages to dry cows and heifers. The dairy herd could be divided into as many as four lactating groups, one group of dry cows and one group of heifers. Forages were the basic feedstuff in the ration. Crude protein and energy of conserved silages were multiplied by a factor of 0.95 before balancing the rations to take into account the usually lower intake of silages with respect to hay (Waldo and Jorgensen 1981). Supplements were estimated in a two-step process. If the forage did not satisfy the energy needs according to National Academy of Sciences–National Research Council (1978) requirements, corn was added to the ration. If the forage-corn mixture did not provide sufficient protein, soybean meal was added.

The experimental conditions for simulation purposes consisted of a three-factor factorial design. Two conservation methods were compared: direct-cut silage (average of 80% moisture content) with the addition of 4 kg of formic acid per ton of wet alfalfa, and wilted alfalfa harvested as soon as the moisture content was below 60% on a wet basis. Two herd sizes were considered: a 70 lactating cow herd and a 140 lactating cow herd. The first herd consisted of 60 cows in lactation, 10 dry cows and 30 replacement heifers. The second herd was double the size of the first herd. Two production levels were considered: 4000 and 7000 kg of milk per lactating cow per year.

All cows weighed 650 kg and yielded 3.5% milk fat, while heifers weighed on average 300 kg and gained 0.5 kg body weight a day. Lactating cows were divided into three groups corresponding to three stages on a typical lactation curve. Rations were established to satisfy the highest nutrient requirement within each stage. Cows producing an average 4000 kg/yr were given rations balanced for 17.6, 14.7 and 10.4 kg of milk a day during each stage, respectively. Cows producing 7000 kg/yr were given rations balanced for 30.8, 25.7 and 18.2 kg of milk a day during each stage, respectively.

Field machinery required for the direct-cut system included three tractors (a 40-kW tractor for transport, a 60-kW tractor for blowing silage into a vertical silo or for piling silage in a horizontal silo, and an 80-kW tractor for the forage harvester), a forage harvester equipped with a cutterbar, two forage wagons and a blower. The wilted silage system required the same machinery as above (with the exception of a windrow pickup unit instead of the cutterbar), and in addition a mower-conditioner, a rake and a small tractor to pull the rake. Machinery investment costs were $103 900 for the direct-cut system and $121 200 for the wilted silage system.

Wilted silage would normally be stored in a vertical concrete silo while direct-cut silage would be stored unpacked on a horizontal concrete platform with a plastic cover. Current cost for medium vertical silos is about $150 per ton of dry matter (TDM). A typical concrete platform (10 m × 60 m) costs $6000 and stores approximately 300 tons of 80% moisture silage, or about 60 TDM. Hence investment cost is $100/TDM. In addition, one plastic cover, 30 m long × 13 m wide, costs about $135 and covers 30 TDM, at an annual cost of $4.50/TDM. This is equivalent to a perpetual fund of $45.00/TDM assuming a 10% interest rate. Therefore, total investment cost for a horizontal silo (platform and plastic) is $145/TDM — very similar to vertical silos. For our analysis, the same investment cost was assumed for both silos. On the smaller farms (70 cows), two silos of 250 tons of dry matter capacity were used, each costing $37 000. On the larger farms (140 cows), two silos of 500 tons of dry matter capacity were used, each costing $57 000 (because of some economies of scale).

The annual cost of owning machinery and structures was calculated as an annuity. Machinery and structures were considered to have accounting lives of 10 and 20 yr, respectively, with no residual value. The interest rate used was 10% a year.

Prices of supplements and of land are important because each system used different amounts of these resources. Prices were based on winter 1984 values: soybean meal cost $350 per ton of dry matter (TDM) and corn cost $200/TDM. Surplus alfalfa was assigned a selling value of $75/TDM. One hectare cultivated with alfalfa was considered to cost about $100 a year for fertilizer, $100 a year for rent and $250 every fifth year for pasture establishment (plowing, seeding). Hence the yearly cost of land was set at $250/ha. Field labor was estimated at $7/man-hour. Formic acid was priced at $1.12/kilogram.

Three cuts were taken each year from the alfalfa pasture. After some suboptimization with the alfalfa growth model, each cut was scheduled to start on 4 June, 21 July and 3 Sept., respectively.

Simulations were run during 10 yr of weather data for Quebec City Airport, between 1967 and 1976. The weather data required for the model included daily minimum and maximum temperatures, total solar radiation and precipitation.

RESULTS AND DISCUSSION

Annual alfalfa yields for three cuts a year are shown in Table I. Alfalfa conserved as direct-cut treated with formic acid and alfalfa conserved as wilted silage lost 19% and 28% dry matter, respectively. Storage losses and feeding losses were about the same for both systems at 7% and 10%, respectively. The main difference between direct-cut and wilted silage lay in field losses totalling 2% and 11% for each system, respectively. In the case of wilted silage, about 60% of the crop was harvested the day after mowing, within 24 h, while the remaining 40% was harvested either within 48 h of mowing or later if rain occurred in the meantime. The average wilting time was 46 h; the average moisture content of wilted silage was 50%.

The average yield in Table I of 12.84 TDM/ha corresponds to very well-established alfalfa in Quebec. For example, in 1983–1984 cultivar trials, the average yield

TABLE 1. SIMULATED ALFALFA YIELDS (METRIC TONS OF DRY MATTER PER HECTARE: TDM/ha), CRUDE PROTEIN (CP) AND TOTAL DIGESTIBLE NUTRIENTS (TDN) AVAILABLE AT MOWING AND AT FEEDING EITHER AS DIRECT-CUT OR WILTED SILAGE

Year	Available at mowing			Conserved as direct-cut with formic acid			Conserved as wilted silage (about 50% moisture content)		
	TDM/ha	CP	TDN	TDM/ha	CP	TDN	TDM/ha	CP	TDN
1967	11.72	0.213	0.689	9.47	0.212	0.687	8.40	0.191	0.664
1968	13.43	0.183	0.653	10.87	0.182	0.652	9.68	0.165	0.630
1969	12.43	0.196	0.668	10.05	0.195	0.667	8.92	0.175	0.634
1970	13.38	0.183	0.651	10.82	0.181	0.650	9.62	0.165	0.631
1971	13.33	0.184	0.651	10.78	0.182	0.650	9.60	0.162	0.621
1972	12.41	0.202	0.676	10.03	0.200	0.675	9.04	0.179	0.653
1973	12.90	0.192	0.664	10.43	0.190	0.662	9.24	0.174	0.638
1974	12.10	0.200	0.670	9.78	0.198	0.668	8.66	0.178	0.633
1975	13.68	0.182	0.651	11.06	0.181	0.650	9.96	0.159	0.621
1976	13.03	0.192	0.665	10.53	0.191	0.664	9.40	0.173	0.643
Average	12.84	0.193	0.664	10.38	0.191	0.662	9.25	0.172	0.637
SD	0.65	0.010	0.012	0.53	0.010	0.013	0.49	0.009	0.013

TABLE II. UTILIZATION OF ALFALFA CONSERVED EITHER AS DIRECT-CUT OR WILTED SILAGE, BY TWO DAIRY HERD SIZES AT TWO PRODUCTION LEVELS. VALUES ARE AVERAGED OVER 10 YEARS.

Number of lactating cows	Average milk production (kg/yr)	Area harvested (ha)	Conserved alfalfa (TDM)	Alfalfa consumed (TDM)	Surplus alfalfa (TDM)
I. Alfalfa conserved as direct-cut with formic acid					
70	4000	45	467.2	412.6	54.6
70	7000	45	467.2	405.2	62.0
140	4000	85	898.8	823.2	75.6
140	7000	85	898.8	790.6	108.2
II. Alfalfa conserved as wilted silage (50% moisture content)					
70	4000	50	462.6	397.6	65.0
70	7000	50	462.6	371.3	91.3
140	4000	95	901.3	764.0	137.3
140	7000	95	901.3	692.9	208.4

TABLE III. ANNUAL COST OF RESOURCES REQUIRED TO HARVEST AND CONSERVE ALFALFA EITHER AS DIRECT-CUT OR WILTED SILAGE FOR TWO HERD SIZES.

	Direct-cut silage		Wilted silage	
	Resources	Annual cost ($)	Resources	Annual cost ($)
70 lactating cows				
1. Machinery investment ($)	103 900.	16 909.	121 200.	19 725.
2. Storage investment ($)	74 000.	8 692.	74 000.	8 692.
3. Fuel (L/yr)	5 179.	2 072.	5 077.	2 031.
4. Machinery repairs ($)	2 419.	2 419.	3 028.	3 028.
5. Field labor (man-hours/yr)	269.	1 883.	394.	2 758.
6. Formic acid (kg/yr)	9 344.	10 465.	0.	0.
7. Alfalfa pasture (ha)	45.		50.	
Land including rotation (ha)	56.25	14 063.	62.5	15 625.
Total annual cost ($/yr)		56 503.0		51 859.0
140 lactating cows				
1. Machinery investment ($)	103 900.	16 909.	121 200.	19 725.
2. Storage investment ($)	114 000.	13 390.	114 000.	13 390.
3. Fuel (L/yr)	9 525.	3 810.	9 551.	3 820.
4. Machinery repairs ($)	4 466.	4 466.	5 684.	5 684.
5. Field labor (man-hours/yr)	497.	3 479.	728.	5 096.
6. Formic acid (kg/yr)	17 975.	20 132.	0.	0.
7. Alfalfa pasture (ha)	85.		95.	
Land including rotation (ha)	106.25	26 563.	118.75	29 688.
Total annual cost ($/yr)		88 749.0		77 403.0

TABLE IV. SUPPLEMENTS REQUIRED TO FEED TWO HERD SIZES AND TWO PRODUCTION LEVELS WITH ALFALFA CONSERVED EITHER AS DIRECT-CUT OR WILTED STAGE

Herd size	Production level (kg/(cow · yr^{-1}))	Purchased corn (TDM/yr)	Purchased soybean meal (TDM/yr)	Surplus alfalfa (TDM/yr)
Direct-cut silage				
70	4000	0.83	0.00	54.59
70	7000	84.01	1.32	61.97
140	4000	3.70	0.00	75.55
140	7000	185.73	4.85	108.19
Wilted silage				
70	4000	15.87	0.00	65.00
70	7000	115.50	3.75	91.26
140	4000	62.94	0.00	137.29
140	7000	275.75	12.53	208.39

was 8.51 TDM/ha for 12 sites throughout the province of Quebec. However, four sites had average yields between 10.11 and 13.08 TDM/ha, with some cultivars yielding as much as 14.2 TDM/ha (CPVQ 1985). The alfalfa model was developed to reflect yield variations due to weather only. Obviously there are other, probably more important sources of variations in yield — quality of establishment, winterkill, weed competition, soil characteristics, type of cultivar. For the purpose of comparing conservation systems, the growth model seemed adequate, with the possible future need to consider lower average alfalfa yields.

The land areas required to grow alfalfa were chosen such that there was a forage surplus at least 9 yr out of 10. With direct-cut, areas required were 45 and 85 ha for the 70 and 140 lactating cow herds, respectively. Under a wilted silage system, it was necessary to have about 10% more land, i.e. 50 and 95 ha respectively, to produce a similar quantity of alfalfa (Table II). Since wilted silage had a lower quality than direct-cut silage, cows could not consume as much alfalfa and required more supplements. Low-producing cows (4000 kg milk/year) consumed more alfalfa than high-producing cows (7000 kg milk/year) because the former have lower nutritional needs which are almost completely met by the forage.

Harvest and conservation costs of direct-cut silage were higher than those of wilted silage (Table III). The cost difference was largely explained by the formic acid which represented almost 20% of the forage conservation cost. Direct-cut had some advantage over wilted silage for other resources: it required less machinery, less land, less fuel and less field labor.

Direct-cut required less feed supplements than wilted silage (Table IV). Corn was purchased in greater amounts than soybean meal because alfalfa was generally adequate for protein requirements but inadequate for energy needs.

Table V compiles total costs of alfalfa production and conservation, and of supplemental feeds for the four dairy herds. At a production level of 4000 kg, the wilted silage system was less expensive than the direct-cut system for both farm sizes. At a production level of 7000 kg, the reverse was true. The higher production cows utilized better the high-quality forage provided by direct-cut.

The cost difference for a 70-cow herd producing 7000 kg of milk/(cow/year) was small, slightly in favor of direct-cut. In Table VI, costs for each conservation system are shown on a year-by-year basis. The standard deviation, or variation was greater for the wilted silage system. The expected costs were similar but the range of costs was greater for wilted silage.

The cost of formic acid used in the direct-cut system was about $10 500 and $20 100 per year to conserve 467 and 899 tons of dry alfalfa, respectively. Since the average annual cost of the direct-cut system was very close to the cost of the wilted silage system (within $2000) just a slight reduction in the cost of acid treatment would make direct-cut silage conservation more attractive. The break-even point is a formic acid treatment cost below $22.50/

TABLE V. TOTAL COSTS OF ALFALFA PRODUCTION AND CONSERVATION, AND SUPPLEMENTAL FEED FOR FOUR DAIRY HERDS UNDER TWO CONSERVATION SYSTEMS (AVERAGED OVER 10 YEARS)

Herd size	Production level ($kg/cow \cdot yr^{-1}$)	Direct-cut silage ($/yr)	Wilted silage at 50% moisture ($/yr)
70	4000	52 575	50 158
70	7000	69 119	69 427
140	4000	83 823	79 694
140	7000	119 478	121 309

TABLE VI. YEAR-BY-YEAR COSTS OF ALFALFA PRODUCTION AND SUPPLEMENTAL FEEDS FOR A 70-LACTATING COW HERD PRODUCING 7000 $kg/(cow \cdot yr^{-1})$ UNDER TWO CONSERVATION SYSTEMS

Year	Direct-cut with formic acid	Wilted silage
1967	67 936	67 509
1968	69 858	70 992
1969	69 750	70 219
1970	70 484	69 946
1971	69 673	72 689
1972	68 676	67 327
1973	68 647	69 042
1974	68 228	71 313
1975	69 613	68 497
1976	68 321	66 734
Average	69 119	69 427
SD	857	1 941

TDM or $4.50 per ton of wet silage at 80% moisture content.

CONCLUSIONS

The difference in total cost between direct-cut silage and wilted silage was small, in the order of $2000 per year or less. The cost difference was sensitive to the price of formic acid. Currently, the break-even point for direct-cut treatment is about $22.50 per ton of dry alfalfa or $4.50 per ton of wet silage.

Year-to-year cost variations are smaller with direct-cut. For example, the range in yearly costs was between $67 800 and $70 500 for direct-cut and between $66 700 and $72 700 for wilted silage, for a 70-cow herd producing 7000 kg of milk/($cow \cdot year^{-1}$). A risk-averse farmer might prefer direct-cut technology to reduce his dependence on weather even though his long-term profit might be the same or even slightly less than with a wilted silage system.

Future research should investigate ways of reducing the amount of formic acid required to preserve wet forage. Light wilting might reduce the acid cost substantially against a low price in the form of field losses. Grasses might benefit more from direct-cut since they have a lower buffering capacity, thus requiring less formic acid and conserving better than wet legumes, such as alfalfa. The cost of storage structures can also be considerably reduced with direct-cut conservation. Instead of a full concrete slab, soil-cement platforms and even soil platforms might result in satisfactory conservation, especially on dry or frozen soils, the latter condition being met 6 mo a year in Northern Quebec. However, little is yet known on the additional losses which might result from a less expensive storage structure.

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REFERENCES

BRUHN, H. D. and R. G. KOEGEL. 1977. More usable protein per acre by a modified forage program. Trans. ASAE (Am. Soc. Agric. Eng.) 20: 653–656.

CABON, G. 1982. Les pertes en cours de récolte et de conservation de la luzerne et du trèfle voilet — aspects économiques de quelques chantiers de récolte. Fourrages 90: 161–180.

CPVQ 1985. Légumineuses fourragères: rapport des essais de cultivars 1984. Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec, Canada G1R 4X6.

FICK, G. W. 1977. The mechanisms of alfalfa regrowth: a computer simulation approach. Search: Agriculture 7(3): 1–28.

KJELGAARD, W. L. 1979. Energy and time needs in forage systems. Trans. ASAE (Am. Soc. Agric. Eng.) 22: 464–469.

McDONALD, P. 1981. The biochemistry of silage. John Wiley and Sons, Ltd., Toronto, Ont.

McISAAC, J. A. and J. LOVERING. 1980. A method for estimating silo losses and costs. Can. Farm Econ. 15(5): 10–16.

NATIONAL ACADEMY OF SCIENCES–NATIONAL RESEARCH COUNCIL 1978. Nutrient requirements of dairy cattle. 5th rev. ed. NAS-NRC, Washington, D.C.

PARSCH, L. D. 1982. DAFOSYM: a model for evaluating the economics of forages on Michigan's dairy farms. Ph.D dissertation. Agricultural Economics Department, Michigan State University, East Lansing, Mich.

REES, D. V. H. 1982. A discussion of sources of dry matter loss during the process of haymaking. J. Agric. Eng. Res. 27: 469–479.

SAVOIE, P. 1982. The analysis of forage harvest, storage and feeding systems. Ph.D. dissertation. Department of Agricultural Engineering, Michigan State University, East Lansing, Mich.

SAVOIE, P., L. D. PARSCH, C. A. ROTZ, R. C. BROOK, and J. R. BLACK. 1985. Simulation of forage harvest and conservation on dairy farms. Agric. Systems 17(2): 117–131.

SHEPHERD, J. B. et al. 1954. Experiments in harvesting and preserving alfalfa for dairy cattle feed. U.S.D.A. Tech. Bull. No 1079. Washington, D.C.

THOMAS, J. W. 1978. Preservatives for conserved forage crops. J. Anim. Sci. 47: 721–735.

WALDO, D. R. and N. A. JORGENSON. 1981. Forages for high animal production: nutritional factors and effects of conservation. J. Dairy Sci. 64(6): 1207–1229.