ENSILING OF POTATO VINES

R. E. Muck, Z. G. Weinberg, D. I. Rouse, B. R. Igl

ABSTRACT. *Potato vines are a potential feed for cattle if the vines can be preserved. The objectives of this study were primarily to study alternative methods to preserve potato vines by ensiling and determine the effects of soil contamination on ensiling. In experiment 1, vines from four potato varieties were harvested individually with a flail chopper set at three heights to vary soil contamination. The chopped vines were ensiled in minisilos alone or amended (3:1, vines to amendment, wet basis) with either chopped alfalfa hay or barley grain. Silos were opened after 90 d for analysis. In experiment 2, vines of one variety were hand-harvested and ensiled fresh or after wilting one day in a greenhouse, alone or in combination with chopped whole plant corn at one of four levels. Silos were opened for analysis after 1, 2, 6, 14 and 90 d ensiling. The vines in both experiments were of high nutritive value with high crude protein contents [194-261 g kg^{-1} dry matter (DM)] and low neutral detergent fiber contents (286-359 g kg^{-1} DM). However, ash contents were relatively high even with low soil contamination (220-307 g kg^{-1} DM) and hand-harvested vines (169 g kg^{-1} DM). In both experiments, unamended vines were poorly preserved, underwent a secondary fermentation, and were unstable aerobically. Little or no lactic acid was present in these silages, acetic acid was the predominant fermentation product, and butyric acid was detected in some silages. In contrast, all three amendments produced well-preserved silages. Barley-amended silages yielded the lowest pHs (4.06 average); alfalfa-amended silages yielded the highest (4.97 average). In a 5-d aerobic stability test, some barley-amended replicates heated while none of the alfalfa- or corn-amended silages heated. Level of soil contamination had no consistent negative effect on fermentation, but the added soil substantially diluted vine dry matter in the high contamination treatments.*

Keywords. *Silage, Potato vines, Soil, Fermentation, Aerobic deterioration.*

Agricultural by-products are residues from both agriculture and the food industry. They may include various peels, shells, pulps, surplus or poor quality fruits and vegetables, and animal excreta. Many of these by-products can serve as feedstuffs for livestock because they are rich in either energy, protein, and/or minerals (Huber, 1980). However, there are likely to be one or more problems associated with their use as a feedstuff. Firstly, some by-products are seasonal in availability, and they may accumulate in quantities larger than needed for immediate use. Secondly, many by-products are quite perishable because they are very moist [< 200 g kg^{-1} dry matter (DM)] and/or high in sugar content. Spoiled or spoiling by-products generally are unpalatable, cause unpleasant odors, and attract insects, rodents, and other vermin. Thirdly, many by-products are highly variable in DM content and quality from day to day, depending on the source. Finally, high moisture content may result in seepage that may pollute water sources and cause environmental damage. Therefore, the use of by-products for animal feeding generally requires some means for adequately storing and preserving the by-product until it can be fed.

By-products can be conserved by drying, through a stabilizing additive, or by ensiling (Kuntzel, 1991). For wet by-products, drying is frequently not economical because of high energy costs relative to the value of the by-product. Similarly, higher levels of stabilizing additives such as propionic or sorbic acids are often required in wet by-products to prevent spoilage, making the cost per unit by-product DM excessive. This may leave ensiling as the only feasible means of storing and preserving some wet by-products.

Because of their composition, by-products are not always ensiled easily. For example, Ashbell et al. (1987) found that orange peel silage had a low DM content and contained high yeast levels that made the silage susceptible to spoilage and large DM losses. Pre-blanching peels or addition of sorbic acid could control the latter problem (Ashbell et al., 1988; Weinberg et al., 1989). However, ensiling orange peels with dry broiler litter resolved both problems (Ashbell et al., 1995).

Potato vines are a potentially attractive by-product for feeding ruminants. Short-term studies with sheep and goats found no problems with palatability of potato vine silage or adverse effects of the glycoalkaloids in the vines

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(Nicholson et al., 1978; Parfitt et al., 1982). Currently in the U.S., approximately 500 000 ha of potatoes are grown, and the vines are killed with herbicides prior to harvest in order to toughen potato skins at a cost of $85 to $125/ha (Muck, 1998). Unfortunately, the dead vines may harbor various potato diseases and other vectors in the field for the succeeding potato crop. Consequently, if vines were harvested, they may not only have feed value but would reduce herbicide and pesticide use in potato production. At an estimated 2.5 t DM ha^{-1} (Klepper and Rouse, 1991), 1.3 million t of vine dry matter would be available annually in the U.S. for feeding if the vines could be conveniently harvested, stored and fed to ruminants.

The most likely means of storing potato vines is ensiling. However, potato vines have a high moisture content, and the hills or ridges in the field on which potatoes are grown make harvesting wilted vines difficult. Earlier work looked at two means of addressing this problem. Parfitt et al. (1982) put the vines through a screw press to dewater the vines to approximately 50% moisture. Unfortunately this process resulted in substantial loss of soluble nutrients from the vines. Nicholson et al. (1978) investigated various additives to vines, including ground barley and chopped hay. However, the levels of addition were insufficient to prevent silage effluent, causing loss of nutrients with potential harm to the environment.

An additional potential problem with harvesting and ensiling the vines is soil contamination. Currently there is no commercial machine designed for harvesting vines, and the level of soil contamination could be quite variable. This could cause additional problems for ensiling because the potential for clostridial fermentation generally is increased by soil contamination (McDonald et al., 1991). Therefore, the objectives of the current work were to (1) determine the composition of potato vines from several varieties, (2) investigate the effects of soil contamination on the ensiling of potato vines, and (3) study alternative ensiling methods to preserve potato vines and prevent silage effluent, based on additives likely to be available on dairy farms.

Materials and Methods

Experiment 1

Vines of four potato varieties (Russet Norkotah, Red Norland, WI 1005, and WI 1099) were harvested on 31 August 1995 from adjacent plots at Prairie du Sac, Wisconsin, with a flail forage harvester set at three different heights to obtain high, medium, and low levels of soil contamination. The chopped vines were ensiled in 473-mL canning jars, alone (300 g fresh weight) or in combination with chopped alfalfa hay (150 g vines, 50 g alfalfa at 910 g DM kg^{-1}) or whole, unprocessed barley grain (195 g vines, 65 g grain at 882 g DM kg^{-1}). The alfalfa was chopped in a stationary chopper with a theoretical length of cut of 10 mm. These ratios of vines to amendments were designed to obtain silages of approximately 300 g DM kg^{-1}. At such a DM content, no silage effluent would be expected in bunker silos (Bastiman and Altman, 1985), and most forage crops ensiled at or above 300 g DM kg^{-1} are unlikely to have clostridial fermentations (Leibensperger and Pitt, 1987). For each silo, the components were weighed, mixed by hand using sterile gloves before ensiling, and packed into a canning jar with a wood dowel. Four replicates per treatment were ensiled. Samples of fresh vines and amendments were taken for analysis in triplicate with the exception of lactic acid bacteria and buffering capacity (one replicate). The silos were stored at room temperature (approximately 22°C). Gas pressure in the silos was relieved periodically during the first week of ensiling by momentarily breaking the seal on the jars. After three months storage, the silos were opened. The silages were sampled for chemical and microbiological characteristics and then subjected to an aerobic stability test lasting five days.

Experiment 2

A single variety of vines (Russet Norkotah) was hand-harvested on 11 September 1995 at Prairie du Sac. Half of the vines were chopped with a stationary chopper (knife configuration like a standard forage harvester; theoretical length of cut, 10 mm) and ensiled in 473-mL canning jars in a similar manner as in Experiment 1. Vines were ensiled alone (300 g) or in various combinations with whole-plant corn at ratios 0:1, 1:1, 1:2, and 1:4 vines to corn, wet basis (200, 250, 240, and 220 g total weight, respectively). The corn was chopped through the same stationary chopper as the vines. Kernel breakage visually appeared to be somewhat less than that obtained with a standard forage harvester although it was not measured. The other half of the vines were wilted on elevated window screening in a greenhouse for 24 h, chopped with a stationary chopper, and ensiled alone (325 g), inoculated with 10^5 lactic acid bacteria g^{-1} crop (*Lactobacillus plantarum* and *Pediococcus cerevisiae*), or in mixtures with whole-plant corn at ratios of 0:1, 3:1, 1:1, and 1:3 vines to corn (200, 280, 260, and 240 g, respectively). The highest ratios of vines to corn were designed to obtain a marginally satisfactory fermentation even though effluent would be expected under practical conditions. The lowest ratios were set to prevent effluent (i.e., approximately 300 g DM kg^{-1}) as well as provide a good fermentation. Like Experiment 1, the components for each silo were weighed and hand-mixed using sterile gloves prior to ensiling. Three samples of the unensiled vines and corn were taken for analysis. Three silos per treatment were opened after 1, 2, 6, 14, and 90 d ensiling and analyzed for chemical and microbiological characteristics. The 90-d silages were tested for aerobic stability also.

Analytical Procedure

The unensiled vines, amendments, and silages were analyzed for similar constituents except as noted. Silages were completely removed from silos and subsampled for analyses. Dry matter content was determined by oven drying for 48 h at 60°C. Ash was obtained after 3 h at 550°C. The dried sample was ground in a cyclone mill to pass a 1-mm screen and used to analyze total nitrogen and fiber content. Crude protein was determined via a Leco FP-2000 analyzer. Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) were measured on unensiled samples only, according to Van Soest et al. (1991). Buffering capacity was determined on unensiled samples as per Muck and Walgenbach (1985).

Wet samples of both unensiled material and silages were processed for a number of constituents. A water extract (1:10 dilution) was used to determine pH, water-soluble

carbohydrates (WSC), lactic acid (LA), and volatile fatty acids (VFA). The WSC were determined by the phenol-sulfuric acid method according to Dubois et al. (1956). LA and VFA were determined on only the silage samples using a high performance liquid chromatograph with a refractive index detector (Muck and Dickerson, 1988). Protein was precipitated from a portion of the water extract using 25% (w/v) trichloroacetic acid (TCA) (20 mL water extract:5 mL TCA). After sitting at room temperature for 1 h or overnight at 4°C, the solution was centrifuged (Muck, 1987). The TCA supernatant was analyzed for soluble NPN using the Leco analyzer, and ammonia nitrogen was determined via autoanalyzer (Broderick and Kang, 1980).

Lactic acid bacteria (LAB) were counted on unensiled materials, inoculants, and silages via pour plate technique using Rogosa SL agar (Difco No. 0480). On all silages in Experiment 1 and the 90-day silages in Experiment 2, yeasts and molds were measured on malt agar (Difco No. 0024, acidified with lactic acid to pH 3.5), bacillus spores on nutrient agar (Difco. No. 0001), and acetic acid bacteria on ethanol yeast extract agar, all according to Muck et al. (1992).

After sampling, the remaining silage from Experiment 1 and the 90-d treatment from Experiment 2 was tested for aerobic stability. Silages were transferred to 473 mL jars surrounded by 5 cm polystyrene. Thermocouples were placed in each jar, and temperatures were recorded continuously for 5 d.

Statistical Analysis

Results in Experiment 1 were analyzed via two-way analysis of variance (variety and soil contamination level) using the General Linear Model procedure within the SAS statistical software package. One-way analysis was used to compare treatments on a given day in Experiment 2. Statistical significance was set at $P < 0.05$ unless otherwise noted.

Results

Experiment 1

Analysis of the fresh vines is given in table 1. The vines were very moist, and plant juices from the vines collected at the bottom of the canning jars during the ensiling of the vine-only treatments. Some significant ($P < 0.05$) varietal differences were observed for all characteristics except ADF and LAB (table 1). The WI 1005 variety, despite the lowest DM content, appeared the most ensilable with the highest WSC content, a low buffering capacity, and the lowest pH. This variety also had the highest NDF and CP contents. Norland appeared to have the poorest ensiling characteristics with next to the lowest WSC content and the highest buffering capacity and pH.

The level of soil contamination had a significant effect ($P < 0.05$) on all of the initial characteristics measured except for LAB ($P < 0.06$). In the highest level of soil contamination, ash content was approximately half of the dry matter (table 1). Buffering capacity, CP, and WSC were reduced approximately one-third in the high soil level relative to the low soil level treatments. Vine pHs were raised on average 0.36, and LAB counts were approximately 10 times higher in the high soil level treatments as compared with the low soil level. The increases in ash content for a given variety going from low to medium to high treatments were not consistent. This was most likely due to variability in hill heights affecting the degree of soil contamination rather than some varietal property.

Table 1. Analysis of the fresh potato vines (Experiment 1); all characteristics as g kg^{-1} DM except as noted

Variety	DM*	Ash	NDF	ADF	ADL	CP	WSC	BC	LAB	pH
Low soil level										
Norkotah	132	262	348	294	51	194	56	376	4.1	6.24
Norland	126	293	319	235	48	221	50	565	3.6	6.62
WI 1005	107	220	359	275	44	260	70	380	3.9	6.17
WI 1099	122	307	286	245	35	224	44	415	3.3	6.32
Medium soil level										
Norkotah	169	371	-†	-	-	158	42	310	4.6	6.49
Norland	167	458	-	-	-	181	36	701	4.9	6.60
WI 1005	118	302	-	-	-	248	51	442	4.0	6.21
WI 1099	153	363	-	-	-	212	40	388	5.0	6.44
High soil level										
Norkotah	226	512	-	-	-	112	34	157	4.0	6.90
Norland	174	489	-	-	-	172	33	478	5.2	6.85
WI 1005	158	509	-	-	-	157	29	249	4.5	6.51
WI 1099	155	490	-	-	-	168	32	369	5.0	6.53
Alfalfa	910	88	511	364	70	177	26	517	3.5	5.96
Barley	882	34	203	52	10	152	14	179	1.6	5.00
s.e.‡	3.1	17.6	12.6	14.1	2.4	5.5	2.3	—	—	0.038

* DM = dry matter, g kg^{-1}; NDF = neutral detergent fiber; ADF = acid detergent fiber; ADL = acid detergent lignin; CP = crude protein; WSC = water-soluble carbohydrates; BC = buffering capacity, meq kg^{-1} DM; LAB = lactic acid bacteria, $\log_{10}$(colony forming units [cfu] g^{-1} crop).
† Not determined.
‡ s.e. = Standard error, n = 3, except only one replicate for BC, LAB.

The primary factor affecting silage quality in Experiment 1 was the amendment. The pH of the final silages averaged 5.75, 4.97, and 4.06 for vines alone, amended with alfalfa, and amended with barley, respectively (table 2). The silages of the vine-only treatments did not contain lactic acid, and their major fermentation product was acetic acid. In approximately half of these silages, butyric and propionic acids were also detected. This varied by variety (data not shown). Norland was the only variety with a consistent presence of butyric

Table 2. Chemical analysis (g kg^{-1} DM except as noted) of the final silages averaged across varieties (Experiment 1)

Soil Level	Amend-ment	DM*	pH	WSC	CP	NPN	Lactic Acid	Acetic Acid	Butyric Acid
Low	None	110	5.93	7.4	179	574	0	100	3.3
	Alfalfa	293	5.07	6.2	196	428	42	48	0.0
	Barley	288	4.04	19.6	187	368	74	13	0.0
Medium	None	139	5.63	6.0	174	496	0	83	3.6
	Alfalfa	319	4.91	6.9	193	389	55	35	0.0
	Barley	313	4.05	22.3	182	362	71	13	0.0
High	None	162	5.70	4.3	127	529	0	67	2.7
	Alfalfa	339	4.94	5.7	170	397	49	33	0.0
	Barley	324	4.09	18.7	172	362	67	14	0.0
S.E.†		2.8	0.120	0.93	4.3	12.9	1.3	1.5	0.34

* DM = dry matter, g kg^{-1}; WSC = water-soluble carbohydrates; CP = crude protein; NPN = soluble nonprotein nitrogen, g kg^{-1} total N.
† S.E. = standard error, n = 16.
Propionic acid was detected in small amounts only in some silages of the unamended vines (5-12 g kg^{-1}); 2,3-butanediol was detected in the silages with barley (2-4 g kg^{-1}).

acid in the vine-only treatments, averaging 8.3 g kg^{-1} DM. The silages with alfalfa and barley had DM contents around 300 g kg^{-1} and had pleasant aromas. The silages with alfalfa had lactic-to-acetic acid ratios of 1:1 to 2:1; whereas, in the silages with barley, this ratio was approximately 5:1. The latter silages also contained small amounts of 2,3-butanediol. Soluble NPN was highest in the vine-only treatments (533 g kg^{-1} total N) and least in the barley-amended silages (364 g kg^{-1}). Residual WSC in the vine-only and alfalfa-amended treatments were similar (5.9 and 6.2 g kg^{-1} DM) and significantly lower than that in the barley-amended silages (20.2 g kg^{-1}).

The primary effect of soil level was dilution of plant DM with ash as suggested by the reduced CP contents at higher levels of soil contamination (table 2). Silage pH and butyric acid levels were not affected ($P > 0.10$) by soil level. Susceptibility to a clostridial fermentation is often associated with soil contamination (McDonald et al., 1991), but that was not observed in this trial. In Norland vines, the vines that were most susceptible to clostridial fermentation, butyric acid content decreased with increasing soil contamination (data not shown). Furthermore, across all varieties and amendment treatments, average lactic-to-acetic acid ratios were lowest for the lowest soil contamination (0.72) and highest for the highest level of soil contamination (1.03), the opposite of what would be expected if soil contamination predisposed the silage to clostridial fermentation. These results suggest the soil had few clostridia although clostridial counts were not made. The only other significant effect of soil was a reduction in soluble NPN at the higher levels of soil contamination (457, 416 and 429 g kg^{-1} total N for low, medium and high soil levels, respectively).

Variety had minor effects on silage quality with some exceptions. As just mentioned the Norland vine-only treatments were more susceptible to clostridial fermentation than the other varieties. The WI 1099 vines had the highest soluble NPN (474 g kg^{-1} total N); whereas, the other varieties had similar levels of NPN (average of 420 g kg^{-1}). Silage pH was not significantly different across varieties. Lactic and acetic acid contents were statistically different, but the ranges were small from a practical perspective (4 and 14 g kg^{-1} DM, respectively).

The major microbial populations were lactic acid bacteria, bacilli, and acetic acid bacteria (table 3). Yeast and mold populations were generally below detectable levels [10 colony forming units (cfu) g^{-1} crop]. Populations generally were affected only by amendment. Bacillus spore counts did vary significantly with variety; they were highest in Norland (5.7 $\log_{10}$ cfu g^{-1}) and lowest in WI 1005 (5.0 $\log_{10}$ cfu g^{-1}). Over five days of aerobic exposure, the silages comprising vines only were the least stable with most replicates heating within that period. Several barley-amended replicates also heated; whereas, the alfalfa-amended silages were stable. Stability was unaffected ($P > 0.10$) by variety or level of soil contamination.

Table 3. Microbiological evaluation of the silages in Experiment 1 after 90-d ensiling, averaged over four varieties and three soil contamination levels [$\log_{10}$ (cfu g^{-1} silage)]

Amend-ment	Lactic Acid Bacteria	Yeasts	Molds	Bacillus Spores	Acetic Acid Bacteria
None	8.0	< 1	1.1	5.4	6.3
Alfalfa	8.1	< 1	< 1	5.6	7.6
Barley	7.2	< 1	< 1	5.0	4.3
S.E. (n = 48)	0.07	—	0.14	0.05	0.13

Experiment 2

Wilting the potato vines for 24 h in a greenhouse under good drying conditions (10 cm or less layer of vines on elevated screening, sunny, temperatures of 25 to 40°C, fans blowing air across the screens) increased dry matter contents only from 117 to 161 g kg^{-1} (table 4). Wilting increased CP and LAB, but other characteristics were unaffected.

Figure 1 shows the changes in pH throughout the ensiling period. Wilting did not prevent a degradation in silage quality in the silages comprising only vines, and pH increased starting from day 14. The LAB inoculant was similarly unsuccessful. The inoculant resulted in a faster decrease in pH in the early stages of ensiling, but the extent of pH decline was insufficient to prevent secondary fermentation. The increase in pH in the vine-only silages was concomitant with the decrease in lactic acid and increase in acetic acid during fermentation (figs. 2, 3). This shift in fermentation products was not necessarily due to clostridial fermentation because butyric acid was detected only in the silages of the unwilted vines (23 ±20 g kg^{-1} DM). The mixtures of vines and corn resulted in high quality silages with pH values less than 4.5 except for the 3:1 mixture of wilted vines to corn.

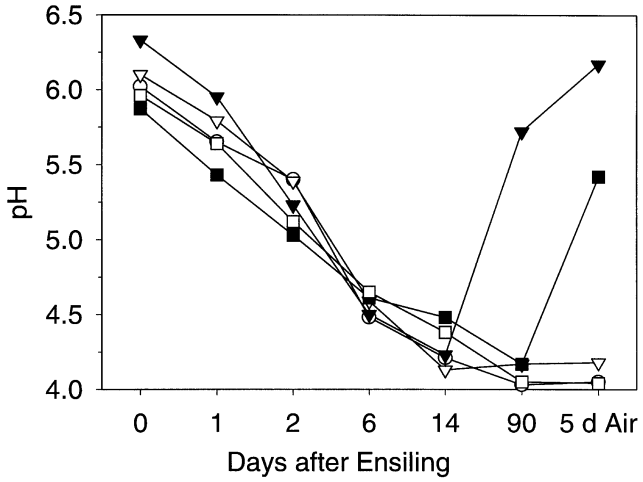
In the vine-only silages the lactic-to-acetic acid ratio was 1:3 to 1:7 (table 5). In most treatments amended with corn, the ratio was 3:1 to 5:1, except for the 3:1 wilted vine to corn mixture. Final silage pH, WSC and soluble NPN for the mixtures were similar to those for corn, again with the exception of the 3:1 wilted vine to corn mixture (table 5) where there were at least strong trends toward differences.

The major microbial populations in the final silages were lactobacilli and bacilli; whereas, yeasts and molds were generally below detectable levels (table 6). After five days of aerobic exposure, yeast numbers increased in the silages of the pure vines and corn; most exposed silages had also substantial numbers of acetic acid bacteria except for the 1V:2C and 1V:4C treatments. Heating patterns during the aerobic stability test agreed with this microbial profile. The silages comprising only vines or corn were the least stable upon aerobic exposure; whereas, none of the

Table 4. Characteristics (g kg^{-1} dry matter except as noted) of the fresh crops (Experiment 2)

Crop	DM*	Ash	NDF	ADF	ADL	CP	WSC	LAB	pH
Fresh vine trial									
Fresh vines	117	169	286	244	47	218	97	2.3	6.33
Corn	362	47	436	248	29	69	43	4.4	5.87
Wilted vine trial									
Wilted vines	161	188	287	247	43	261	93	4.4	6.16
Corn	355	46	471	284	41	71	54	5.4	5.84
S.E. (n = 3)	9.0	9.8	21.1	14.3	3.6	6.4	7.5	0.45	0.136

* DM = dry matter, g kg^{-1}; NDF = neutral detergent fiber; ADF = acid detergent fiber; ADL = acid detergent lignin; CP = crude protein; WSC = water-soluble carbohydrates; LAB = lactic acid bacteria, $\log_{10}$(cfu g^{-1} crop).



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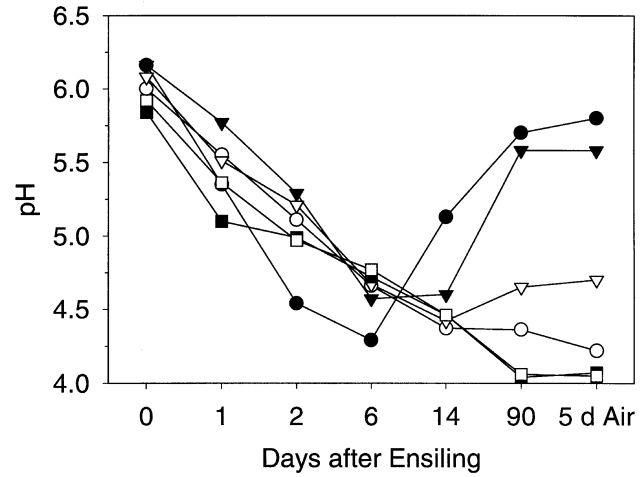
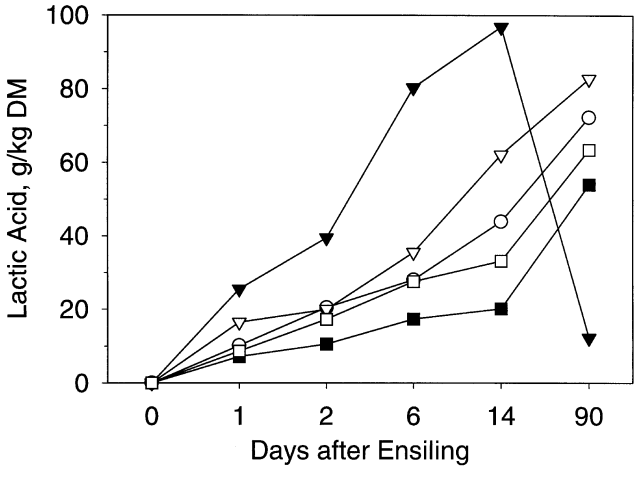


(b)

Figure 1–The pH of potato vine silages, alone or amended with whole-plant corn, during ensiling and after 5 d of aerobic exposure: (a) fresh vines, (b) wilted vines. Treatments: t vines, l inoculated vines, n corn, t highest vine mixture (1 Vine:1 Corn, 3V:1C for A, B, respectively), m medium mixture (1V:2C, 1V:1C for A, B), o lowest mixture (1V:4C, 1V:3C for A, B).



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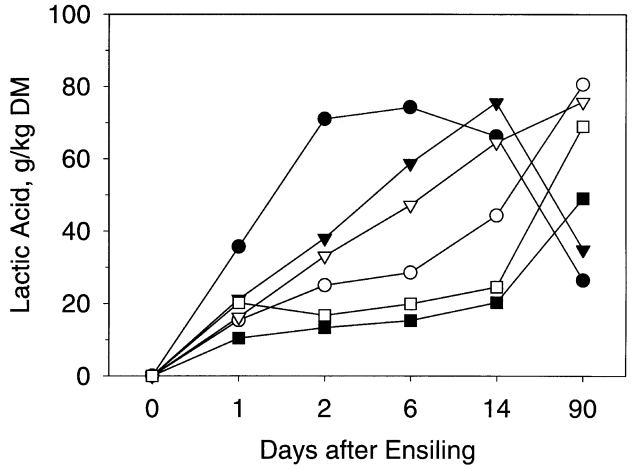


(b)

Figure 2–The lactic acid content of potato vine silages, alone or amended with whole-plant corn, during ensiling: (a) fresh vines, (b) wilted vines. Treatments: t vines, l inoculated vines, n corn, t highest vine mixture (1 Vine:1 Corn, 3V:1C for A, B respectively), m medium mixture (1V:2C, 1V:1C for A, B), o lowest mixture (1V:4C, 1V:3C for A, B).

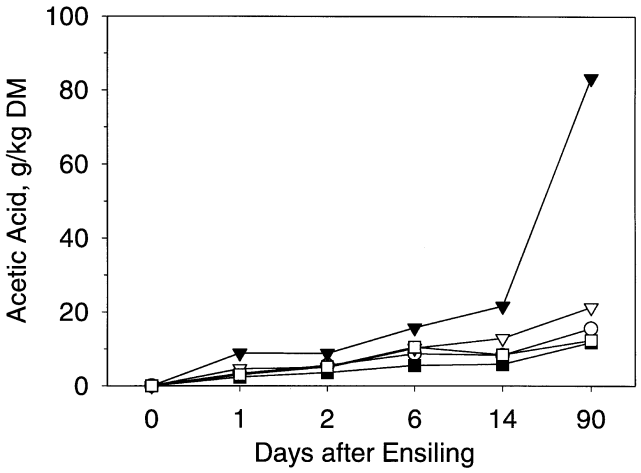
mixed silages heated over the five-day aerobic stability test. Similarly, a significant rise in pH during aerobic exposure occurred only in the silages containing just vines or corn (fig. 1).

Discussion and Conclusions

Potato vines have the potential to be used as feed because the high crude protein and the low fiber contents compensate for the high ash levels. The vines in our study were somewhat higher in quality than those reported in earlier studies. The CP of our fresh vines with low soil contamination ranged from 190 to 260 g kg^{-1} DM. In contrast, Nicholson et al. (1978) harvested two varieties of potato vines weekly for five weeks and observed a range in crude proteins from 80 to 210 g kg^{-1} DM with most vines at 120 to 180 g CP kg^{-1} DM. The low CP contents in that study were associated with later harvests (15 September in New Brunswick, Canada). Parfitt et al. (1982) reported a CP of 180 g kg^{-1} DM for fresh Russet Burbank vines. The ADF content of our vines were similar to those reported by Nicholson et al. (1978) with values in both studies primarily between 230 and 300 g kg^{-1} DM.

Varietal differences in vine quality were observed in Experiment 1. The varieties were grown on adjacent plots of the same soil type and under the same environmental conditions so that differences between varieties most likely represent true varietal differences. However, because our experiment was carried out for only one year at one location, it is not possible to determine if such differences would be consistent from year to year or from one location to another.

The harvested vines alone were consistently too low in DM and sugar contents to achieve a sufficiently low pH to prevent secondary fermentation. For the low DM contents of the vine-only treatments, the pH would need to be less than 4.0 to prevent a clostridial fermentation



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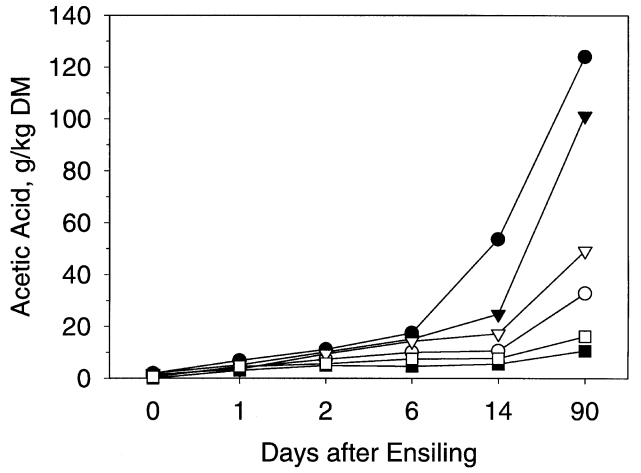

(b)

Figure 3–The acetic acid content of potato vine silages, alone or amended with whole-plant corn, during ensiling: (a) fresh vines, (b) wilted vines. Treatments: t vines, l inoculated vines, n corn, t highest vine mixture (1 Vine:1 Corn, 3V:1C for A, B respectively), m medium mixture (1V:2C, 1V:1C for A, B), o lowest mixture (1V:4C, 1V:3C for A, B).

(Liebensperger and Pitt, 1987). In Experiment 2, the pH of the vine-only and inoculated treatments dropped only into the mid to low fours, permitting clostridial activity. While clostridial activity was possible in all of the vine-only treatments, butyric acid was not consistently present; whereas, acetic acid levels were always high and lactic acid levels low. This suggests the activity of lactic acid bacteria utilizing lactic acid after sugars were exhausted and producing acetic acid as has been observed in low DM, low WSC grass silages (Rooke, 1991). Similar to our results, Nicholson et al. (1978) found that the pH of ensiled Belleisle vines declined to 4.00 after two weeks; however, after six weeks pH had risen to 4.56. The lactic-to-acetic acid ratio in those vine silages after six weeks was 0.6, further suggesting a secondary fermentation. Another potential problem with unamended vines would be silage effluent. This was not a factor in our laboratory scale silos, but it would be in actual silos.

Table 5. Chemical analysis (g kg^{-1} dry matter except as noted) of the final silages (Experiment 2)

Mixture	DM*	pH	WSC	CP	NPN	Lactic Acid	Acetic Acid	Ethanol
Fresh vine trial								
All vines	101	5.72	6	231	599	12	83	9
All corn	365	4.17	18	78	412	54	12	19
1V:1C	233	4.17	7	131	390	83	21	9
1V:2C	255	4.03	11	98	406	72	16	8
1V:4C	299	4.05	15	82	465	63	12	9
s.e. (n = 3)	13.7	0.090	2.3	12.4	39.9	10.2	5.0	2.0
Wilted vine trial								
All vines	145	5.58	11	254	692	35	101	11
All corn	342	4.04	18	70	496	49	11	17
3V:1C	199	4.65	11	180	586	76	49	11
1V:1C	234	4.36	14	153	510	81	33	10
1V:3C	300	4.06	15	116	482	69	16	10
Inoculated vines	150	5.70	18	254	691	26	124	10
s.e. (n = 3)	15.4	0.175	6.0	29.2	57.2	6.2	12.5	2.4

* DM = dry matter, g kg^{-1}; WSC = water-soluble carbohydrates; CP = crude protein; NPN = soluble nonprotein nitrogen, g kg^{-1} total N; V = vines; C = corn.

Butyric acid was detected only in the silages of the fresh vines (23 ± 20 g kg^{-1}), propionic acid in the fresh vine trial silages of the all vines and all corn treatments (both at 3 g kg^{-1}), and traces of 2,3-butanediol were detected in the all corn silages in the fresh vine trial.

Table 6. Microbiological characteristics [$\log_{10}$ (cfu g^{-1} silage)] of the silages (Experiment 2)

	90-Day Silages			After 5 Days Aerobic Exposure			
Mixture	Lactic Acid Bacteria	Yeasts	Bacillus Spores	Yeasts	Molds	Bacillus Spores	Acetic Acid Bacteria
Fresh vine trial							
All vines	7.6	< 1	4.8	4.5	2.8	5.5	4.5
All corn	7.1	2.7	5.4	7.6	< 1	6.2	3.4
1V:1C*	7.3	< 1	4.4	2.8	< 1	4.9	5.4
1V:2C	6.7	< 1	4.5	< 1	1.2	4.8	1.5
1V:4C	6.1	< 1	4.9	1.8	1.5	5.0	1.4
s.e. (n = 3)	0.32	0.60	0.25	1.36	1.14	0.36	1.2
Wilted vine trial							
All vines	8.0	< 1	5.4	3.2	3.0	4.9	4.7
All corn	6.8	2.4	4.4	7.3	< 1	4.8	4.0
3V:1C	7.7	< 1	5.1	1.1	1.2	4.5	3.2
1V:1C	7.5	< 1	4.4	< 1	1.3	4.6	4.1
1V:3C	7.2	< 1	5.2	1.5	3.5	4.6	4.8
Inoc. wilted vines	8.0	< 1	4.8	5.1	4.9	5.0	5.6
s.e. (n = 3)	0.43	0.50	0.44	1.14	1.24	0.19	1.26

* V = vines; C = corn.

Mold and acetic acid bacteria counts were all below detectable level (< 1) in the 90-day silages.

Wilting of vines could eliminate both poor fermentation and effluent problems. Nicholson et al., (1978) found that wilting to 300 g DM kg^{-1} produced stable vine silages of low pH, but acetic acid content was greater than that of lactic acid. In our investigation, wilting the vines for one day under hot, dry conditions in a greenhouse only increased DM content by 44 g kg^{-1} and still did not permit adequate preservation. The leaves on the top surface of the vines dried, but both leaves and stems on the underside, even though lying on a screen, remained wet. This suggests some form of turning would be needed for adequate field drying. However, since potatoes are grown on hills, tedding or raking wilted vines is impractical, if not impossible. The addition of a LAB inoculant to the wilted vines was also ineffective because it could not decrease the pH low enough to prevent secondary fermentation. A similar

pattern was observed when a LAB inoculant was tried in moist pea vine silages (Weinberg et al., 1993).

High quality silages of potato vines were obtained only in mixtures with drier crops, which also diluted ash levels. All three amendments (alfalfa hay, barley grain, and whole-plant corn) produced good silages (of sufficiently low pH to prevent clostridial fermentation and sufficient DM content to eliminate effluent concerns). Of the three amendments, barley produced the lowest pH and alfalfa the highest. The corn- and barley-amended silages produced high lactic-to-acetic acid ratios (4 to 5:1) except in the wilted vine mixtures. In contrast, the alfalfa silages had low but acceptable lactic-to-acetic acid ratios, averaging 1.25. Soluble NPN was reduced by all three amendments and was below 50% of total N with the exception of two wilted vine-corn mixtures; whereas, in the vine-only silages soluble NPN ranged from 50 to 70% total N. Overall, the effects of the amendments were greater than that observed by Nicholson et al. (1978). In their experiments, a 5% addition of ground barley grain or a 14% addition of timothy hay on a wet basis had little effect on lactic-to-acetic acid ratios or soluble NPN although pHs remained stable at approximately 4.0 over six weeks of fermentation in these amended silages. Perhaps the reduced effects in their study were due to their lower levels of amendments. Also, it should be noted that their addition levels would have been insufficient to prevent effluent concerns.

The amended silages in our study were also more resistant to aerobic spoilage than the vine-only silages. None of the alfalfa- or corn-amended silages heated in five days of aerobic exposure. Several of the barley-amended silages began to heat, but there was no consistent trend as to variety or soil contamination level. The heating in barley-amended silages relative to the other amendments was probably due to higher levels of residual starch and sugar which enhance spoilage rates (Muck et al., 1991). In Experiment 2, the mixtures of vines and corn were more stable aerobically than either the corn- or vine-only silages, suggesting some synergistic effects. The microbiological analyses in both experiments indicated that acetic acid bacteria may be a factor in initiating aerobic deterioration of vine silages as has been found in corn silages (Spoelstra et al., 1988).

Perhaps the most surprising aspect of our investigation was that soil contamination level had relatively little practical effect on preservation. We anticipated that higher levels of soil contamination would cause greater clostridial fermentation based on the observations of others (McDonald et al., 1991). It is unclear why there were no substantial negative effects in the current study. Perhaps the soil had low levels of clostridial bacteria. Maybe the higher LAB counts in the higher soil contamination treatments (table 1) offset higher clostridial levels. Even in the absence of a negative preservation effect, soil contamination should be kept at a minimum because the high ash content of soil dilutes the feed value of the vines. Even the hand-harvested vines in Experiment 2 had much higher ash contents than any of the amendments. A high ash content would not prevent the vines from being fed but may limit the level of vines in a cattle ration. The development of a harvester more suitable than a flail chopper would certainly be desirable to minimize soil contamination.

Overall from our experiments, potato vines can be ensiled successfully if mixed with another crop that primarily will raise dry matter content to a level that minimizes effluent potential (300 g DM kg^{-1} for bunker silos) and has a sufficient sugar content to help insure a good fermentation. Because the vines are so wet, a mixture which produces a minimum DM content of 300 g kg^{-1} invariably will contain more amendment than vines. In our study, alfalfa hay and barley grain represented approximately two-thirds of the dry matter in both their mixtures. In the 1 unwilted vines:4 corn mixture which produced a 299 g DM kg^{-1} silage, corn dry matter was 12 times the vine dry matter in the mixture. Consequently, one might better consider the vines as an amendment to another crop being ensiled. The best option would be to co-ensile the potato vines with a crop which is harvested at the same time, such as an early maturing corn. This would minimize the labor for harvesting and storage. Mixing with corn would also have the advantage of complementing the low crude protein content of the corn and producing a silage that is more aerobically stable than corn silage.

Further research is needed prior to adoption of feeding ensiled potato vines to cattle and other ruminants. As indicated above, machinery to efficiently harvest vines with minimal soil contamination is needed. Secondly, longer term feeding studies than those done by Nicholson et al. (1978) and Parfitt et al. (1982) are required to determine if any toxic problems exist. Finally, pesticide regimens for potatoes may need to be altered if the vines are fed. This may lead to additional research on means of controlling insects and diseases in potatoes such that the vines do not contain levels of pesticide residues at harvest that would prevent their being fed.

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