MACERATION: THE PROCESS AND NUTRITIONAL IMPLICATIONS

Tim Kraus[1]

ABSTRACT

Intensive or severe conditioning of forage crops (sometimes called "maceration") greatly reduces the field-drying time required to reach moisture levels suitable for harvesting as hay or as silage. In addition, severely conditioning alfalfa has been shown to increase alfalfa digestibility by 10% or more. Because of the many small fragments resulting from intensive conditioning, the forage has been pressed into a continuous cohesive strip called a "forage mat". Prototype machines which (1) mow, (2) macerate, (3) form "mats" and (4) place them on the stubble have been built by research and development groups.

Key Words: alfalfa, maceration, drying rate, digestibility, feeding trials

INTRODUCTION

Since the beginning of livestock domestication, there has been a need to produce high quality forages. The ability to understand the physiological processes that occur within the living cell and to exploit the physical laws that govern the natural world has allowed man to make vast improvements in forage quality. Traditionally, three primary methods have been used to achieve high forage quality. First, plant breeding has allowed the selective cross-breeding of plant species to create new varieties having characteristics which improve forage quality. Second, increased knowledge of plant physiology has resulted in the development of cutting schemes that have vastly improved forage quality. Lastly, an advanced understanding of the physical laws of nature has allowed both improved harvesting systems and storage structures to be developed. These improvements have resulted in faster and more efficient harvesting machinery, again enhancing forage quality. Historically, these methods have been used either alone, or more commonly, in conjunction to improve forage quality. However, recent research has shown that severe mechanical disruption of the plant (maceration) can significantly reduce dry matter loss and increase forage utilization by increasing the drying rate of forage, enhancing fermentation rates for silage preservation, and improving forage digestibility. This new mechanical processing technique may prove to be an effective tool for enhancing forage quality.

Process and Equipment

Maceration is a process in which the physical structure of plant stems are broken down and split into numerous pieces while the leaves and upper stem segments are crushed and pureed. The process greatly increases a plant's specific surface area, disrupts many plant cell walls, and abrades the waxy cuticle of the epidermis all of which reduce the resistance of water movement from the plant to the surrounding environment. Once macerated, the plant material is pressed into a cohesive mat which is intended to prevent leaves and upper stem segments from falling through the stubble and coming in contact with the ground. The technique reduces field losses while maximizing the potential for increased drying rates.

Product Engineer, New Holland North America, Inc., New Holland, Pennsylvania

Typically, there are two mechanical processes commonly used to macerate forages. One method is to pass the plants between a series of closely spaced rolls having roughened surfaces and different peripheral speeds (Fig. 1). The differential speed between the roll surfaces shears the plant stems longitudinally and severely abrades the waxy cuticle of the epidermis. The level of conditioning is controlled by the number of rolls, the relative speed of the rolls, and the space between the rolls. Higher degrees of conditioning are achieved by increasing the number and relative speed differential of the rolls and by decreasing the space between the rolls (Shinners et al., 1988a).

Another method is to strike the plants with a blunt object traveling at a high speed. Striking the material in this manner ruptures cell walls and destroys the physical structure of plants. The level of conditioning is controlled by changing the speed and the number of impacts. This method can be used independently or in conjunction with other mechanical conditioning mechanisms, such as a pair of crushing rolls, to produce the desired level of conditioning and the physical characteristics needed to form cohesive mats (Fig. 2) (Kraus, 1990).

Several prototype mat machines have been constructed (Koegel et al., 1988; Deutz Fahr, 1992; Shinners et al., 1992; Savoie et al., 1993; Asselin et al., 1994; Tietz, 1995) one of which is shown schematically in Figure 3. The maceration and mat formation process consists of four stages: (1) the standing crop is cut and conveyed to the macerator unit; (2) the crop is macerated (i.e., severely conditioned or shredded); (3) the macerated material is passed through a press where a thin, continuous mat is formed; and (4) the mat is deposited onto the field stubble. The mats of macerated forage can then be harvested by either baling or chopping when the appropriate moisture content is reached.

In order to achieve near-optimum drying rates and minimize field losses mats of macerated forage should be dense and not much thicker than 3/8 inch. For heavy crops, such as first cutting alfalfa, this results in the mats being spread over about 70% of the cut area. For lighter subsequent cuttings, mats would cover 50% or less of the cut area.

Because stems are generally split into many slender ribbons or fibers, and the leaf and stem materials are homogenized, they tend to dry at a common rate. This largely eliminates the problem of leaves over-drying and shattering while waiting for stems to dry adequately. Small plant fragments are generally "pasted" within the mat structure by the drying plant juice. Therefore, with proper equipment, harvesting losses can be kept to a very modest level.

Mats have been formed and pressed in a variety of ways generally involving drums, rollers, and carrier belts (Fig. 4). The mat press, regardless of its configuration, should fulfill several requirements: (1) its surface speed must match ground speed to allow mats to be laid intact onto the stubble, (2) mats should be supported as close to the stubble as possible, since their wet strength is not great, (3) the mats should be held under pressure for as long as practical to improve their consolidation and strength, and (4) the pressing rolls or surfaces should provide grooves or depressions to allow the plant juice a location for momentary "escape" while the fibrous material is being forced together. As soon as pressure is released from the mat, any free juice is instantly reabsorbed. There is a common misconception that the press used to form the forage mat removes juice from the plant material much like the wringer rolls on a washing machine. This is not the case; all plant juice remains with the mat. Fast drying is the result of the juice being exposed to the evaporative process.

Mat thickness is an important factor in determining drying rate. It is necessary that mat thickness be kept reasonably uniform to eliminate damp spots, especially when mats are harvested as dry hay. This requires that the press be fed as uniformly as possible from the macerator. If the forage is being ensiled, then mat uniformity is of less importance as long as the final average moisture content is suitable.

Shinners et al., (1987) compared field-drying of mats of macerated alfalfa with that of conventionally conditioned alfalfa under very good drying conditions. (Fig. 5) In this study the macerated matted forage reached a moisture content of 20% in less than five hours. In the case of silage-making, a suitable moisture content was reached in about two hours. In either case, the mat process allowed the alfalfa to be mowed and harvested the same daylight period. As drying conditions become less favorable, the differences in drying rates between mats of macerated material and conventional material become less dramatic, and under bad conditions there may be little difference.

Feeding Trials

A number of feeding trials have been conducted over a period of years comparing animal utilization of severely conditioned alfalfa with that of conventionally harvested material. The results have consistently shown that animals are able to utilize the severely conditioned material to a greater extent.

Early feeding trials were carried out with sheep and goats, because of the relatively small amounts of severely conditioned forage available. Table 1 gives the results of two feeding trials with sheep (Koegel et al., 1992) comparing mat-harvested alfalfa hay with conventionally harvested material. Dry matter intake was increased by 6.1% and 4.9% and NDF digestibility was increased by 12.8% and 17.8%. A trial with lactating goats comparing the same materials (Table 2) showed the following increases for mat-harvested material: dry matter intake, 5.7% milk production 12.1%, and protein production 5.3%. Table 3 shows the results of two later sheep feeding trials comparing mat-harvested and conventional alfalfa silage (Koegel et al, 1992). In the first trial the mat-harvested material showed an improvement in dry matter digestibility of 15.9% and in the second trial it showed an advantage in weight gain per unit feed of 18.8%.

Table 1. Digestibility trials with alfalfa hay on sheep.

	Control	Mat	% Difference
Trial 1. Eight wethers for 12 weeks			
Dry matter intake, kg/d	1.15[b]	1.22[a]	6.1
Apparent NDF digestibility, %	43.0[d]	48.5[c]	12.8
Trial 2. Four wethers for 4 weeks			
Dry matter intake, kg/d	1.22	1.28	4.9
Apparent NDF digestibility, %	35.3[d]	41.6[c]	17.8

[ab] Means in rows with different superscripts differ ($P < 0.10$).
[cd] Means in rows with different superscripts differ ($P < 0.05$).

Table 2. Digestibility trials with lactating goats fed on 60% alfalfa hay and 40% grain (10 goats for 4.5 weeks.)

	Control	Mat	% Difference
Dry matter intake, kg/d	2.44[b]	2.58[a]	5.7
Milk, 4% fat corrected, kg/d	3.3[b]	3.7[a]	12.1
Protein, kg/d	0.103[b]	0.108[a]	4.9

[ab] Means in rows with different superscripts differ ($P < 0.10$).

Table 3. Digestibility trials with alfalfa silage fed ad libitum, to sheep.

	Control	Mat	% Difference
Trial 1. Eight sheep for 6 weeks (digestion stalls)			
Ave. dry matter digestibility, %	59.68	69.18	15.9
Daily dry matter intake % body weight	3.42[a]	4.49[b]	31.3
Trial 2. Twenty-six sheep for 2 weeks (pen of 13)			
Daily dry matter intake, % body weight	2.65	3.02	14.0
Ave. weight gain, kg	2.98[c]	3.68[b]	23.5
kg gain/kg dry matter	0.149	0.177	18.8

[ab] Means in rows with different superscripts differ ($P < 0.10$).

In the first feeding trial done with lactating cows, (Koegel et al., 1992) no milk production advantage was found (Table 4). However, the cattle fed the mat-harvested alfalfa silage had an increase in body weight more than four times that of the control group. Taking into account milk produced, weight gain, and energy for maintenance, it was calculated that the cattle had derived about 10.8% more energy from the mat-harvested silage than from the conventional silage. Based on this and other results, it was believed that mat-harvested forage could be used to replace some of the grain in dairy rations while maintaining production at or near the genetic potential of the cattle.

Table 4. Digestibility trial with lactating cows fed 65% alfalfa silage and 35% concentrate (12 cows for 8 weeks).

	Control	Mat	% Difference
Milk production, kg/d	24.5	24.2	n.s.d.
Fat, %	3.7	3.5	n.s.d.
Body weight increase, kg/d	0.08[a]	0.44[b]	450
Dry matter intake, kg/d	19.9	19.6	n.s.d.
Calculated energy from forage, MJ/kg	4.61	5.11	10.8

[ab] Means in rows with different superscripts differ ($P < 0.10$).

A recent feeding trial appears to substantiate this belief (Mertens, 1995). In this trial two groups of twelve cattle each were selected for equal production. Prior to the trial both groups were fed a relatively high grain:forage ration typical of production practice. At the beginning of the trial both groups were gradually switched to rations higher in forage and lower in grain. As can be seen in Figure 6, after a brief adjustment period, the cattle receiving mat-silage were able to maintain approximately the level of production they had on the previous higher grain ration and to out-produce the cattle on the conventional silage ration 7-8%.

In addition to showing consistent advantages in the energy derived from mat-harvested forages, feeding trials have also shown indications of increases in the level of bypass protein (that protein which escapes the rumen undegraded allowing more efficient utilization in the gut) for mat-harvested forages relative to conventional forages. Yang et al., (1993) showed an increase of estimated bypass protein of 21% for mat-harvested alfalfa hay relative to conventionally harvested alfalfa hay. Mertens (1993) found a decrease in rumen ammonia for mat-harvested alfalfa hay and silage relative to conventionally harvested material of 23.9% indicating less ruminal protein breakdown for the mat harvested alfalfa. Alternately, greater ruminal fermentation of forage carbohydrate may have supported more incorporation of ruminal ammonia into rumen microbes.

Kraus et al., (1997a) studied the effects of mechanical conditioning on the kinetics of forage digestion, to understand how mechanical conditioning improves forage digestibility. In this study they used a method based upon measuring the electrical conductivity of the leachate from the plant material, to measure the extent of cellular rupture due to various mechanical treatments (Kraus et al., 1997b). Alfalfa was conditioned to four different levels. For treatment 1 the alfalfa was not conditioned. For treatment 2 the alfalfa was conditioned using a conventional mower-conditioner. For treatment 3 the alfalfa was severely conditioned using a crushing impact macerator (Fig. 2). For the fourth treatment the crop was severely macerated using a rotary impact macerator (not shown).

Fresh samples of each treatment were placed into polyester bags and *in situ* dry matter (DM) and neutral detergent fiber (NDF) disappearance from each bag was measured at 6, 12, 24, and 48 h. The kinetics of DM and NDF digestion were analyzed using a simple first-order kinetic equation with the addition of a discrete instantly soluble DM fraction and a discrete lag time, respectively. Figure 7 is a plot of DM disappearance vs. digestion time for each treatment. Relative to the unconditioned material (28 µS/cm), conditioning with intermeshing rubber rolls (60 µS/cm) increased the instantly solublized DM fraction from 0 to approximately 11%. Similarly, the crushing-impact treatment (518 μS/cm) increased the instantly solublized DM fraction to nearly 34%.

Figure 8 is a plot of NDF disappearance, as a fraction of total DM, vs. digestion time for each treatment. Relative to the unconditioned material (28 μS/cm), conditioning with intermeshing rubber rolls (60 μS/cm) reduced the lag time from 8.7 to approximately 4.5 h. The crushing-impact treatment (518 μS/cm) decreased the lag time to approximately 1.5 h. The rotary impact treatment (992 μS/cm) allowed the fiber to begin digesting immediately.

The DM digestion model suggests that mechanical conditioning of plant tissue ruptures cells which allows intercellular constants to be instantly solublized. The NDF digestion model suggests that mechanical conditioning decreased the lag time associated with the digestion of fiber. The lag time associated with fiber digestion in the model may reflect the time required for microbes to penetrate cells and begin digestion from the interior surface of the cells. Mechanical conditioning allowed rumen microflora which produce the enzymes for fiber digestion, easier access to the inside of the cell wall and thereby allows them to attach more quickly. This allows the microbes more time to digest cell walls and subsequently derive more energy from the forage before it is passed to the abomasum of the digestive tract.

In another study, Kraus (1997) studied the effects of conditioning level and crop maturity on the digestibility of alfalfa. In this study, alfalfa was harvested at 3 stages of growth late vegetative, late bud, and late flower. All three cuttings were mechanically conditioned to four different levels and the extent of cellular rupture of each treatment was measured using the leachate conductivity method described. *In situ* DM disappearance was measured at 6, 12, 24 and 48 h according to the methods previously described.

Figures 9 and 10 are plots of DM disappearance vs. conditioning index (CI) at 6 and 12 h of digestion for alfalfa cut at late vegetative, late bud, and late flower stages of growth, respectively. At these digestion times, there was a direct linear relationship between level of conditioning and DM disappearance. At digestion times of 24 h or greater, DM disappearance values converged.

The initial concentration of NDF of the alfalfa cut at late vegetative, late bud, and late flower stages was 35.6, 46.0, and 48.0, respectively. Figure 9 illustrates that at 6 h of digestion disappearance of DM from late flower alfalfa with a CI of 70% was similar to late bud and late vegetative alfalfa conditioned to 40 and 10%, respectively. Likewise, 10 illustrates that at 12 h of digestion disappearance of DM from late flower alfalfa with a CI of 75% was similar to late bud and late vegetative alfalfa conditioned to 50 and 12%, respectively. These results suggest that mechanical conditioning may mitigate the effect of crop maturity with respect to forage digestibility, allowing forages to be harvested at later stages of growth which may in turn increase crop yields, increase return on machinery investment, and improve stand persistence.

<u>**Harvesting and Storage**</u>

As stated earlier, intensively conditioned forages may be stored and fed either as silage or as dry hay. In either case the first step is to pick up the forage from the stubble. In early trials, it appeared that the conventional tine-bar pick-up tended to break the mats leading to excessive losses. As a result a belt and tine pick-up was developed which could be used with either a baler or a forage harvester (Fig. 11). This pick-up was similar to those used with combines used to pick up swathed grain. Recently a second type of pick-up has been developed for picking up mats. This pick-up consists of a rapidly rotating rotor with plastic paddles enclosed by a suitable housing. In addition to the paddles lifting and throwing pieces of the mats, the paddles create an air stream which appears to vacuum small fragments from the ground. A pick-up unit of this type was made by replacing the rotor of a flail chopper with a plastic paddle rotor. This unit retained the cross auger and blower (which did minimal chopping), so that it could be used to pick up and convey the mats to a trailed wagon for subsequent ensiling.

Because of the very compliant nature of severely conditioned or macerated alfalfa, it was found that when ensiling good packing was obtained without chopping (Shinners et al., 1988). However, to improve handling characteristics into and out of the silo and in TMR mixers, some minimal chopping might be considered desirable. Muck et al., (1989) found that in ensiled alfalfa, mat-processed material fermented nearly twice as fast as conventionally processed material, reaching final pH in half the time or less.

The compliant nature of mat-processed alfalfa is also apparent when baling. This has allowed 20%-50% more dry matter to be packed into a bale of a given size (Straub et al., 1989). The authors' experience has been limited to small rectangular bales, however.

If rained on, forage mats retain their integrity. However, leaching loss (loss of soluble carbohydrates) may be 3-5 times that of conventionally conditioned material (Rotz 1990). The probability of being rained on, however, is minimized by the short dry-down time.

The upper surface of forage mats tend to bleach while drying in sunlight. Because the mats are dense, only a small amount of material in the uppermost layer is affected. After the mats have been broken up in the harvesting process, bleaching is generally not perceptible.

Equipment Development

European manufacturers have taken the lead in development of equipment for intensive conditioning. The Deutz-Fahr Company of Germany has had working prototypes for about five years. These are self-propelled machines that shred the forage using a roughened roll macerator (Fig. 1). While farm publications have printed dates for the commercial debut of this machine as early as 1996, this did not occur. Two companies, the Greenland Group of the Netherlands and Krone of Germany have introduced intensive forage conditioning machines to the market. While these machines condition more intensively than conventional machines, they do not condition as intensively as the work reported in the U.S. and they do not form the forage into a cohesive body like a mat. They appear to be adapted to grass only and the production of silage only. Since conditioning is less severe than the work reported here, it is not known whether there would be any improvement in forage digestibility. None has been claimed to date.

Two Canadian research groups are active in the development of equipment for intensive conditioning. They are Agriculture Canada at the University of Laval at Quebec and the Prairie Agricultural Machinery Institute near Winnipeg. The former group has developed several

Shinners, K. J., R. G. Koegel, and R. J. Straub. 1987. Drying rates of macerated alfalfa mats. Trans. ASAE 30(4):909-912.

Shinners, K. J., R. G. Koegel, and R. J. Straub. 1988. Consolidation and compaction characteristics of macerated alfalfa used for silage production. Trans. ASAE 31(4):1020-1026.

Shinners, K. J., T. J. Kraus, R. G. Koegel, and R. J. Straub. 1992. A crushing-impact macerator, beltless press forage mat formation machine. For presentation at Agricultural Engineering 1992, Agricultural Engineering International Conference, Uppsala-Sweden.

Straub, R. J., R. G. Koegel, and K. J. Shinners. 1989. Harvesting systems for macerated mat dried alfalfa. ASAE Paper 89-1511. St. Joseph, Michigan 49085.

Tietz, N. 1995. One-day hay edges closer. Hay and Forage Grower. Vol. 10(2):37-38

Yang, J. H., G. A. Broderick, and R. G. Koegel. 1993. Effect of heat treating alfalfa hay on chemical composition and ruminal in vitro protein degradation. J. Dairy Sci. 76:154-164.

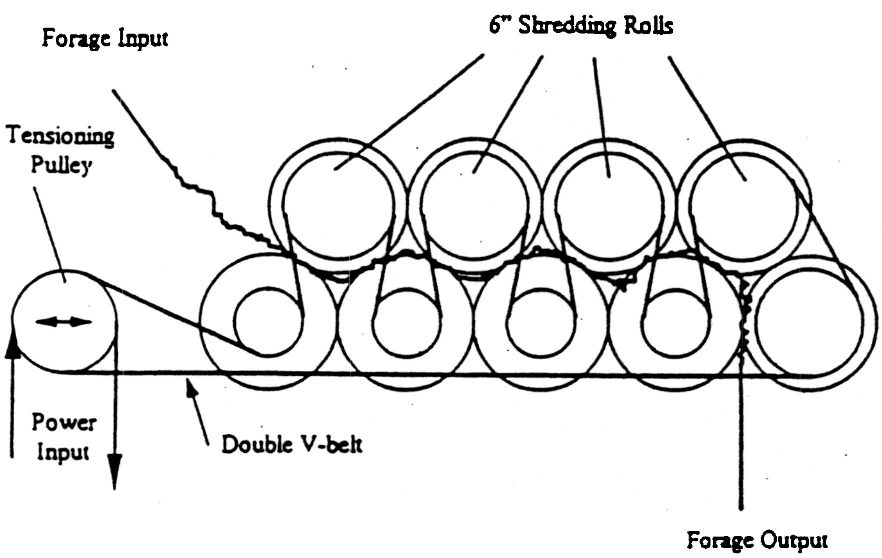

Figure 1. Schematic of Roughened - Roll Macerator.

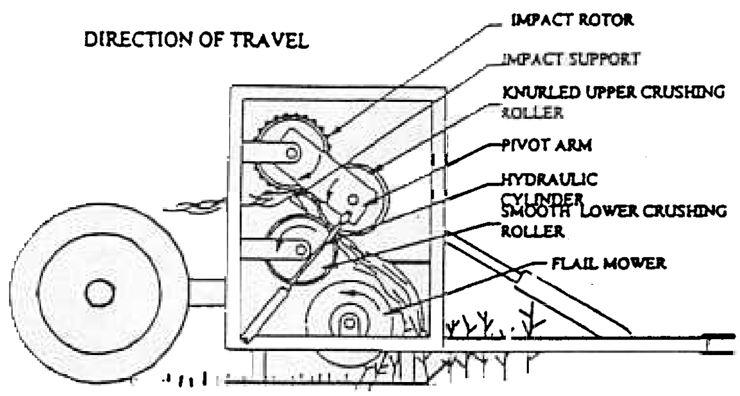

Figure 2. Schematic of Crushing-Impact Macerator with Flail Mower.

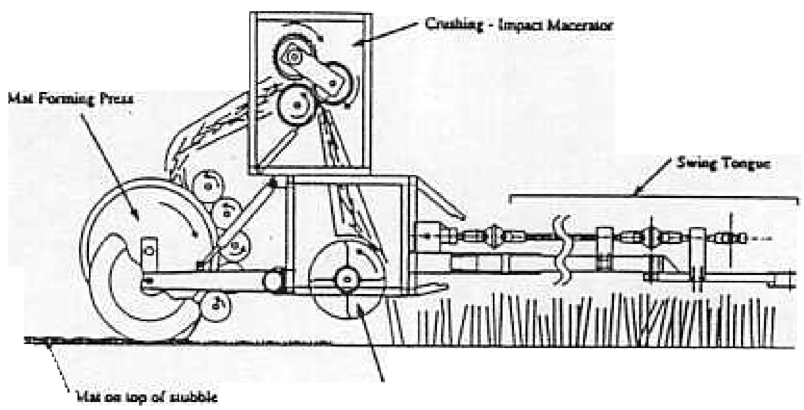

Figure 3. Schematic of Mat Machine (Shinners et al., 1992).

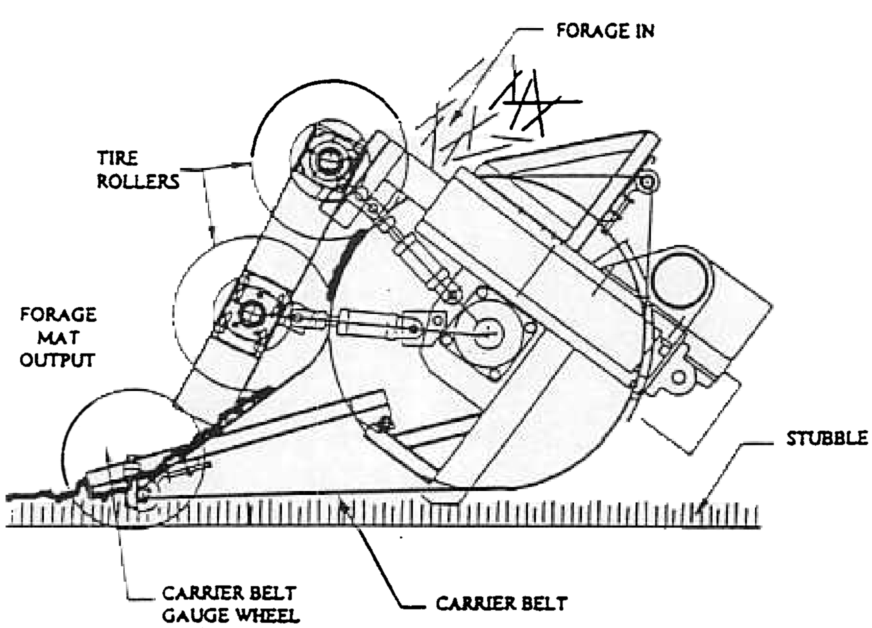

Figure 4. Press for Forming Mats of Macerated Forage (Nelson, 1997?).

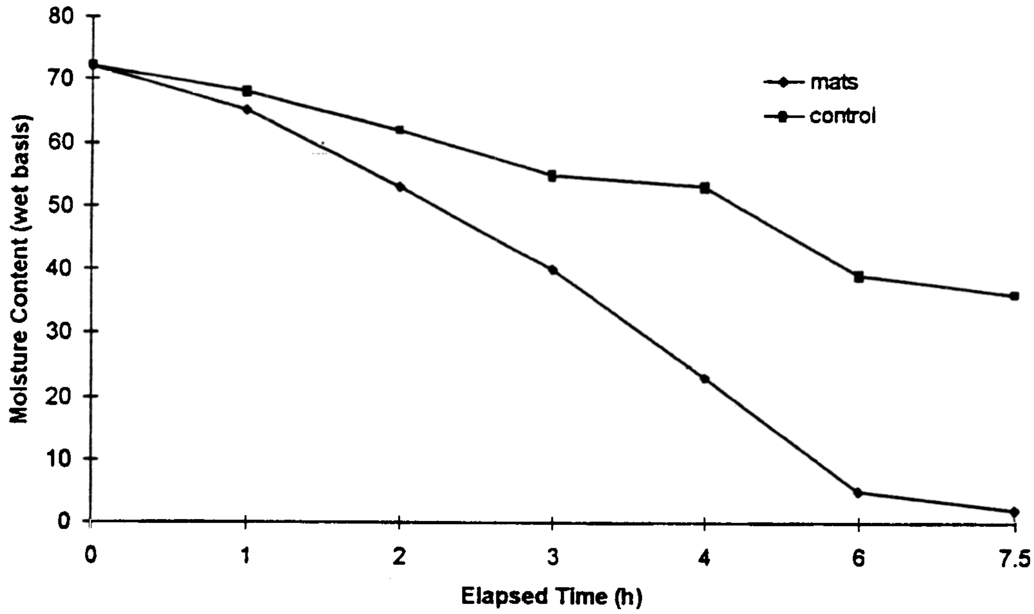

Figure 5. A Comparison of Drying Rates for Mat-Processed and Conventionally Conditioned Alfalfa (Shinners et al., 1987)

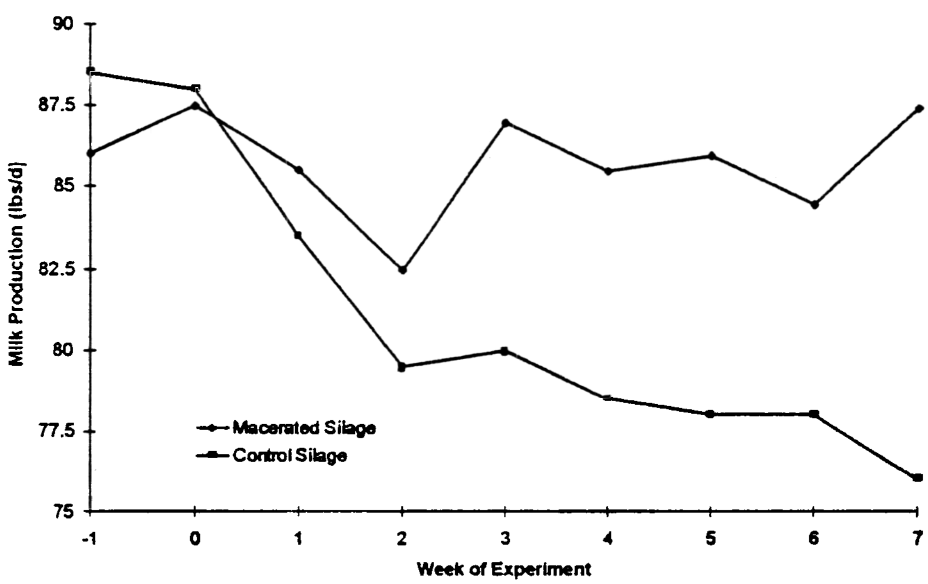

Figure 6. 1995 Lactation Study Comparing Macerated and Conventionally Conditioned Alfalfa Silage

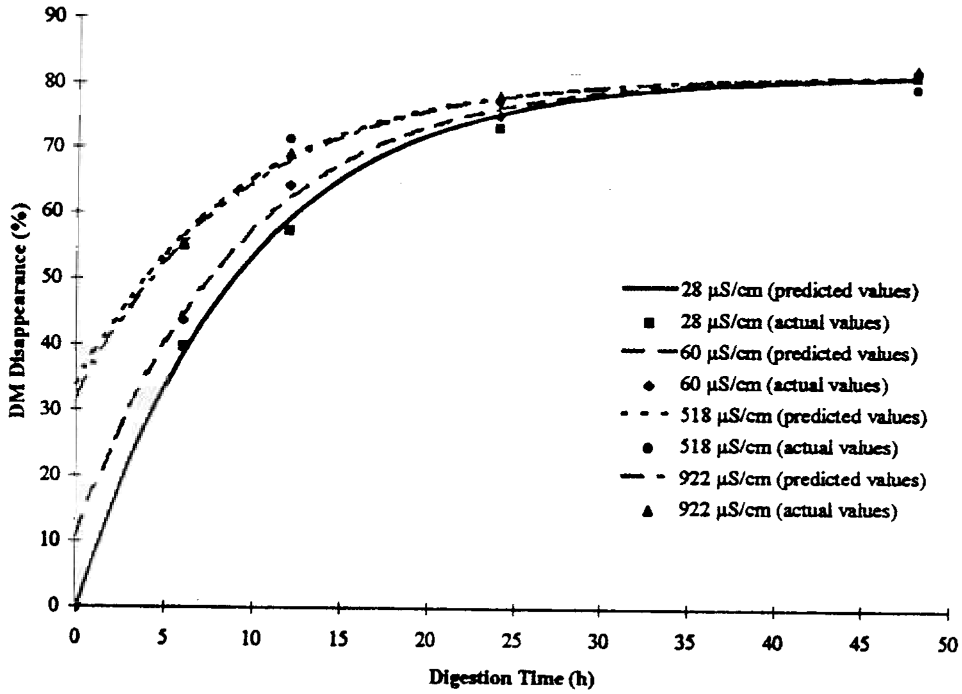

Figure 7. Digestion Time vs. DM Disappearance of Alfalfa as Affected by 4 Levels of Conditioning as Measured by Leachate Conductivity.

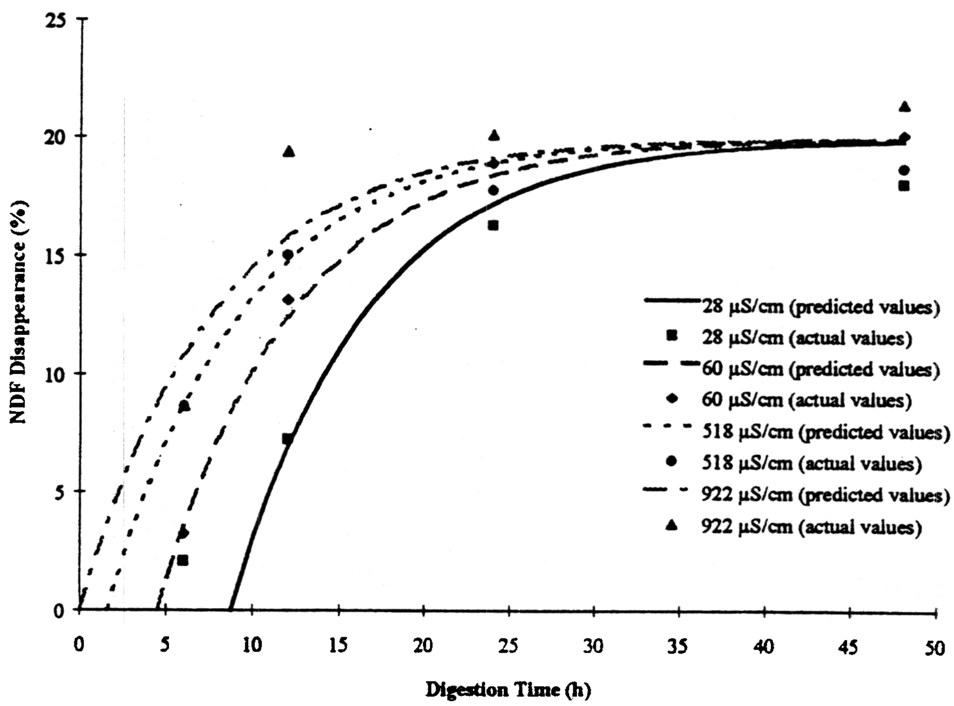

Figure 8. Digestion Time vs. NDF Disappearance of Alfalfa as Affected by 4 Levels of Conditioning as Measured by Leachate Conductivity.

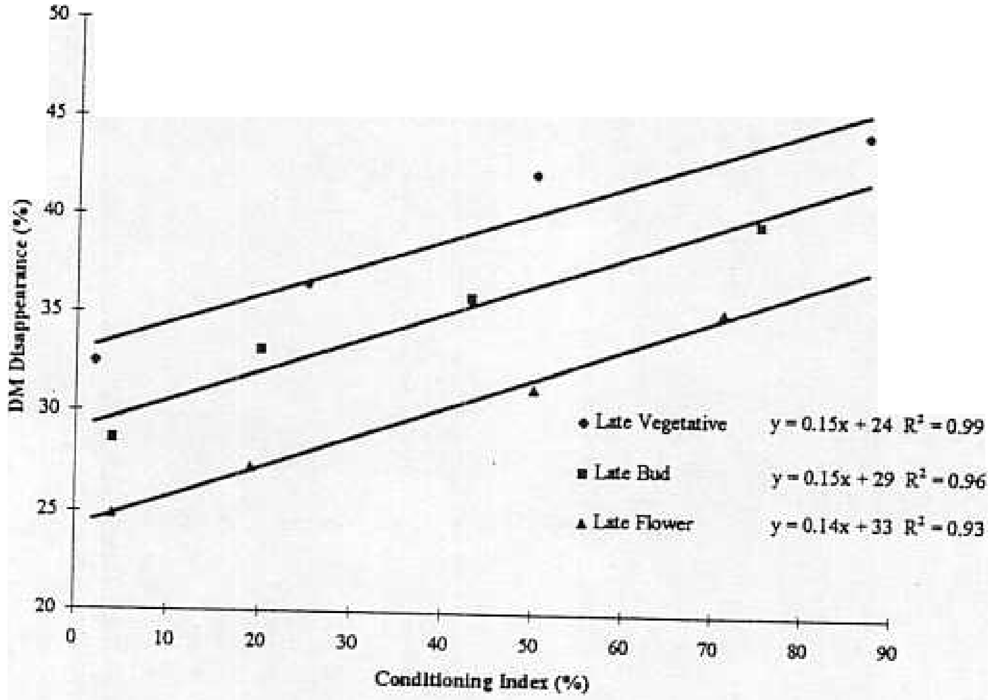

Figure 9. DM Disappearance vs. Conditioning Index at 6 h Digestion for Alfalfa at 3 Stages of Growth.

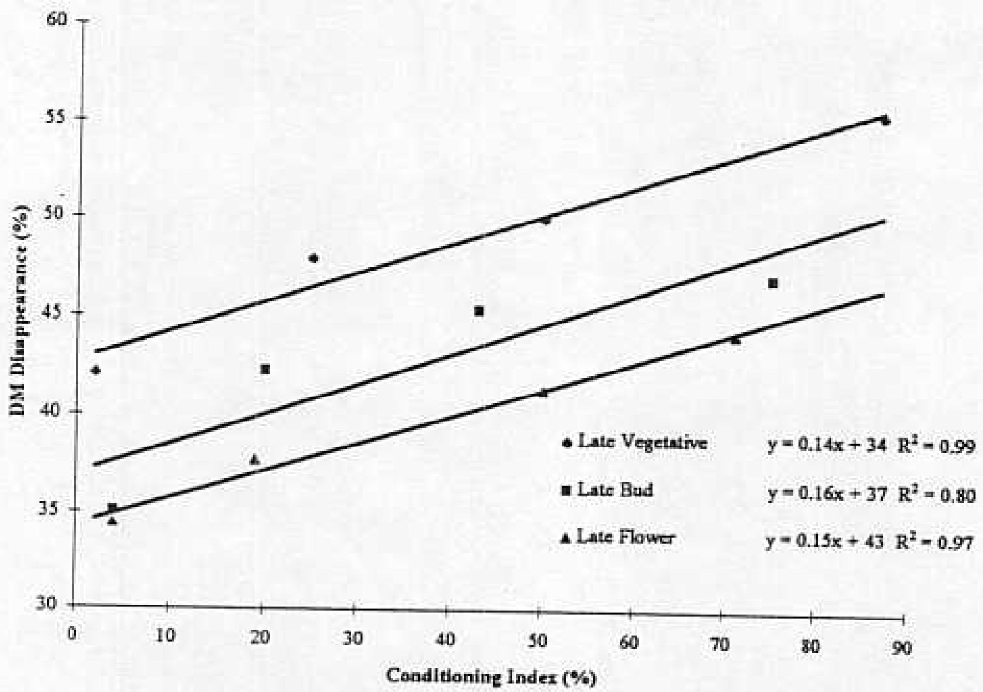

Figure 10. DM Disappearance vs. Conditioning Index at 12 h Digestion for Alfalfa at 3 Stages of Growth.

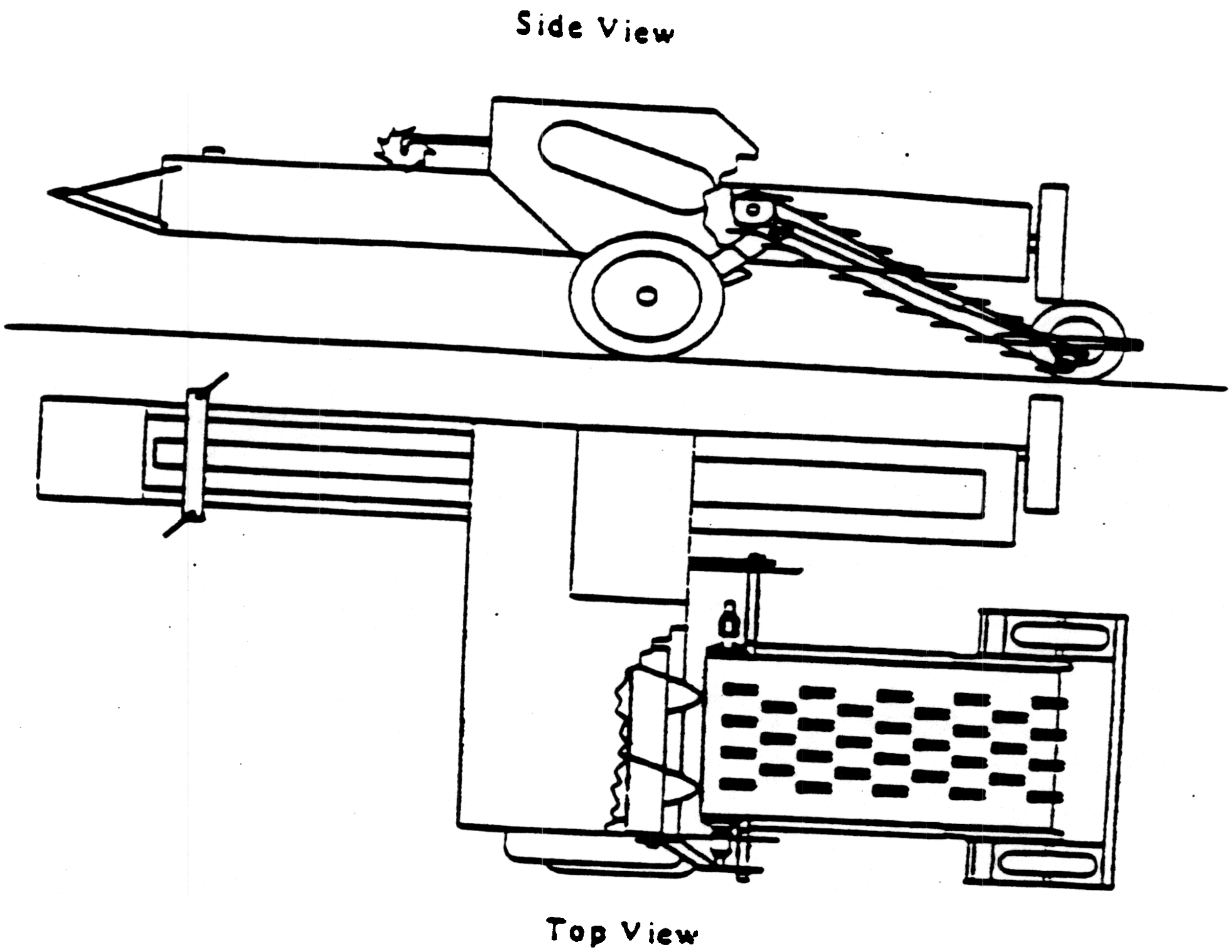

Figure 11. Belt and Tine Pickup for Forage Mats Mounted on Conventional Small Rectangular Baler.

machines including both trailed and self-propelled units and has carried out feeding trials showing improved performance of intensively conditioned forage. The latter group has developed a pull-type machine which is currently undergoing evaluation.

REFERENCES

Asselin N., P. Savoie, J. Lajoie, and D. Tremblay. 1994 Evaluation of intensive forage conditioning on a disk mower. ASAE Paper No. 941520. St. Joseph, Michigan 49085.

Deutz Fahr Corporation. 1992. Brochure of new mat machine.

Koegel, R. G., K. J. Shinners, F. J. Fronczak, and R. J. Straub. 1988. Prototype for production of fast-drying forage mats. Transactions of the ASAE 4(2):126-129.

Koegel, R. G., R. J. Straub, K. J. Shinners, G. A. Broderick, and D. R. Mertens. 1992 An overview of physical treatments of Lucerne performed at Madison, Wisconsin for improving properties. J. Agric. Engng. Res. 51, 183-191.

Kraus, T. J. 1990. Development of a Crushing - Impact Forage Maceration Device. Unpublished MS thesis. Agricultural Engineering Department, Univ. of Wisconsin - Madison.

Kraus, T. J., R. G. Koegel, D. R. Mertens, and R. J. Straub. 1997a. Intensive mechanical forage conditioning: relationship to increased animal utilization. ASAE Paper No. 971085. Minneapolis, Minnesota.

Kraus, T. J., R. G. Koegel, R. J. Straub, and K. J. Shinners. 1997b. Leachate conductivity as an index for quantifying level of forage conditioning. ASAE Paper No. 971100. Minneapolis, Minnesota.

Mertens, D. R. 1993. Personal communication, USDA-ARS, Dairy Forage Research Center, Madison, WI.

Mertens, D. R. 1995. Personal communication, USDA-ARS, Dairy Forage Research Center, Madison, WI.

Muck, R. E., R. G. Koegel, K. J. Shinners, and R. J. Straub. 1989. Ensilability of mat-processed alfalfa. Proceedings 11th Intl. Congress on Agric. Engineering, Dublin.

Rotz, C.A., R. G. Koegel, K. J. Shinners, and R. J. Straub. 1990. Economics of maceration and mat drying of alfalfa on dairy farms. Transactions of the ASAE 6(3):248-256

Savoie, P., Binet, G. Choinere, D. Tremblay, A. Amyot, and R. Theriault. 1993. Development and evaluation of a large-scale forage mat maker. Transactions of the ASAE 36(2):285-291.