During the past year, MF (Massey-Ferguson) marketed a wafering machine which is one of the significant developments in the field mechanization of forage crops.

Wafering provides a potential for a complete handling system from field to feed. At present, the majority of farm labor is involved in handling of feeds for livestock. The reduction of labor around the farmstead provides the impetus for the acceptability of wafering. This is one of the main reasons why wafering has been subjected to considerable development activity over the past decade (2,4,9).

The impact of a new machine like the hay packer will be slow as it involves the conversion of present facilities to handle the requirements involved in a total systems concept. The latest developments of wafering shall be reviewed in the following.

DEFINITION OF A WAFER
A wafer is primarily a highly agglomerated mass of unground hay where the particle length of a percentage of particles is greater than the least dimension of the mass (8,10). Pellets have been referred to as agglomerated forages whose ingredients have been ground and sized. Herein lies the basic difference between a wafer and a pellet.

MECHANISM OF WAFERING
The exact mechanism or theory of wafering is not entirely understood. Why legumes wafer more readily than loose or baled hay after drying that wafers retain Vitamin A better than loose or baled hay after drying and storage. This may be attributed to the exclusion of air in the wafer (14).

The machine variables which affect the wafering are:
- Die pressure.
- Hold time in the die.
- Percent water added.

From a physical quality standpoint, dense wafers withstand abuse in handling without excessive deterioration into fines. They are more economical to transport but are more difficult to dry. For animal acceptability, density is no problem if the wafer is small and bite-size. Cattle will consume wafers with unit specific weights (specific weight of individual wafers) up to 40 lbs/cu ft but will reject large dense wafers if they are unable to break the wafers into smaller pieces. As a comparison, dense pellets are readily consumed by animals even though the unit specific weights are 60-70 lbs/cu ft.

Wafers contain a good distribution of long fibers and provide the necessary roughage to prevent any adverse effects on butterfat yield in dairy cattle. Wafers with specific weights up to 40 lbs/cu ft will readily disintegrate in the animal's stomach or rumen for good digestibility. Consequently, unit specific weights of 30-40 lbs/cu ft appear to be the optimum densities for good durability, animal acceptance and digestibility. The corresponding bulk specific weights of the wafers are 25-35 lbs/cu ft.

The quality of the hay wafer depends on crop maturity and the extent of field drying. These conditions hold true for baled hay. However, there is research evidence to indicate that wafers retain Vitamin A better than loose or baled hay after drying and storage. This may be attributed to the exclusion of air in the wafer (14).

PRODUCTION OF WAFERS
The MF 48 Hay Packer is shown in figure 1. A description of the operating principle of the machine has been published in previous literature (1,8). Wafers are formed by extruding forage under pressure through a number of dies (figure 2). The waters produced are approximately 2 1/4 x 2 1/4 inches with lengths varying from 2 to 6 inches. A small amount of water is added and mixed with the material before the latter enters the dies. The water is necessary in making a wafer by this process.

The preparatory processes or field operations for curing hay are similar for both the hay packer and baler. The crops can be cut with a mower or a flat chopper and windrowed. An even windrow is highly desirable to provide more uniform drying and a smoother feed into the machine. Field experience indicates that alfalfa hay wafers best with a moisture content between 11-15 percent. Research and development is being conducted to extend the moisture range for wafering.

The addition of moisture during the wafering process produces an end product coming out of the machine with a higher moisture content. For example, the water added may increase the initial moisture content of 15 percent to 21-23 percent dependent on the skill of the operator. This high moisture content necessitates drying of the wafers to 14 percent for safe storage.

A study of the labor requirements based on a favorable operation in the state of Washington last fall indicated that a total of 1 to 1.1 manhours is required to harvest, store and feed 1 ton of wafers (8). The operations were wholly mechanized. Studies carried out by different research centers indicate that up to 1.86 manhours...
per ton are required to harvest baled hay (7). These figures show the possible potential saving in manpower with wafering.

**STORAGE AND HANDLING**

Forage crops have always presented problems for handling in and out of storage because of the poor flow characteristics. In addition, the majority of farmsteads are not mechanized. The introduction of wafers presents a product adaptable to bulk or mass handling techniques. New buildings and facilities are desirable to provide proper storage, drying and handling of wafers. Major drawbacks are encountered in trying to adapt them to existing buildings which, in many cases, are outmoded. Nevertheless, many systems are now working with mechanized arrangements utilizing available materials handling equipment.

Wafers do not flow like grain or even like pellets. Handling equipment incorporating dump or scoop features minimizes the hand labor. A specially designed dump wagon, the MF Hi-Lift Dump Trailer, capable of handling 3 tons, has proven satisfactory for transporting wafers (figure 3). This trailer is equipped with forced air ventilation to cool and reduce the moisture content.

![Figure 3: View showing Hi-Lift dump trailer unloading wafers into truck.](image)

Storage facilities may vary from large concrete slabs to enclosed structures. Necessary precautions must be taken in storing wafers to prevent the local accumulation or concentration of fines to insure proper air circulation (figure 4).

During the wafering process, considerable energy is imparted to the wafer. Water temperatures as high as 140-150°F have been recorded as the wafer leaves the machine. On cooling, the wafers harden and set. To minimize and reduce the quality of fines, it is desirable to limit the amount of handling until the wafers are cool.

**DRIYING**

In most cases, wafers come out of the machine at moisture contents above the safe level for storage. Drying was found necessary for wafers when the moisture content was above 14 percent. In semi-arid regions with low humidities, wafers with moisture contents up to 18 percent may be stored without artificial drying. The rate of drying is found to be dependent on initial moisture content and the bulk specific weight (figure 5).

![Figure 5: Effect of unit specific weight on drying rate. (Michigan State University).](image)

![Figure 6: Effect of air temperature on drying rate. (Michigan State University).](image)

This is expected since drying depends on moisture diffusion through the mass. The resistance of wafers to air flow is low. With a ½ foot height of wafers, the plenum pressure is in the order of .32 inches water for an air flow rate of 20 cfm/sq ft (6).

Drying should be initiated within 48 hours of wafering. In climates where the relative humidities exceed 75 percent continuously, artificially heated air may be necessary for satisfactory drying since the moisture equilibrium for hay at that relative humidity and ambient air temperature may be above 15 percent. Heated air greatly accelerates the rate of drying (figure 6) (13). Drying of wafers does not present a technical problem.

The main difficulty lies in educating the farmer that high quality forages can be obtained with artificial drying.

**FEEDING OF WAFERS**

Present practices of handling wafers from storage to feed are relatively simple. Wafers may be loaded by elevator or scoops onto a feeding wagon for easy distribution into feedbunks. Self-feeders are being tried experimentally but there is insufficient experience to indicate their success.

Cattle have no trouble consuming wafers once they become accustomed to them and want far less hay as wafers than as long loose hay. Many farms have experienced gains in intake and food conversion with wafered hay. Steers experience higher weight gains per day with wafers than with baled hay.

Many comparison feeding trials show that wafers will not adversely affect butterfat production in dairy cattle. Wafers will perform as well as long hay. On the other hand, cows fed ground and pelleted hay have shown slight reduction in butterfat percentage (12).

The threshold average particle size which causes butterfat depression has not been established. Butterfat depression is known to occur with particle lengths below 3/4 inch and does not occur with particle length above two inches. Extensive activity in research is being carried out to determine the threshold size and its required percentage distribution in a wafer to prevent butterfat reduction.

**CONCLUSION**

The impact on farming with a wafering machine is slow in realization. It is well to remember that the wafering machine forms only part of a forage harvesting, storage and feeding system. Its introduction involves considerable changes to present techniques and processes in addition to the user educational program.

More research is required to obtain a better understanding of the basic wafering process. The effect of both entrained and externally added moisture needs to be determined. The moisture range for wafering must be extended. This and other information will lead to development of better forage handling systems.

There can be little doubt that with increasing farm sizes and livestock production in the future an end product such as a wafer, which permits a wholly mechanized material handling system, will become highly popular.

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results for draft control with those for position control. It should be noted, however, that the rear wheel reaction for draft control is greater than for position control, whereas the draft is greater for position control. Referring to figure 5 and comparing the force in link 2 for draft control and in link 2 for position control, one will note the greater variation and higher peaks for the run in draft control. These rapid fluctuations and high peaks of force in the hanger links for draft control are undoubtedly caused by the hydraulic system of the tractor adjusting to varying draft conditions by raising and lowering the plow slightly and probably account for the greater wheel reaction in draft control. Because of the approximations made in computing the standard deviations, it is impossible to compute a confidence interval for the average resultant components. A rough estimate of the upper limit may be made by adding to the average resultant, twice its standard deviation, and similarly a lower limit by subtracting twice the standard deviation. A statistical test was not used to compare the average resultants in draft control and position control because the standard deviations of the average resultants and position control are large enough in themselves to indicate no difference at a 5 per cent level except perhaps with a vertical component.

Table 5 compares the tractor wheel reactions under several conditions. The reactions given for plowing with a pull type plow was calculated, assuming that the draft of the pull type plow was the same as the mounted plow and the drawbar was pulling horizontally at a 15-inch height. It should be noted that the rear wheel reactions determined in this study are 20 to 25 per cent greater for the mounted plow than those calculated for a pull type plow while the front wheel reactions are essentially the same. This study shows that under the conditions of the test the sum of the wheel reactions of the tractor was greater than the total weight of the tractor and plow. This is probably not true for all implements. A comparison of the calculated standard deviations of the resultant horizontal components for draft control and position control shows that the draft control mechanism does keep the draft almost constant. This is also evident from the appearance of the charts (see link 3, figure 5). The method of obtaining the link forces in a three-point implement hitch outlined in this study appears to be quite satisfactory. Strain gages can be attached to links readily and it is not difficult to calibrate the links. If strain recording equipment is already on hand, the method is not expensive. Application of statistical techniques makes possible estimates of the reliability of the mean chart deflections used in calculating forces and their resultants.

REFERENCES


WAFERING IN FORAGES

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REFERENCES


