3. If cross cultivation is properly done, worthwhile cultural benefits are obtained.

4. The check-row planter resulted in a further savings because it reduced the amount of seed used which amounts to about $2.00 per acre at the present time.

5. In making a comparison of yields under the various methods in the Red River Valley and Mason City areas, it has been shown that beets grown under cross cultivated or check-row methods, slightly out-yield beets produced under the old method.

In conclusion, special recognition should be made of the work performed by the late C. T. Lund, who was Chief Agriculturalist of the American Crystal Sugar Company at the time, as it was largely due to his willingness to try new methods, that these methods were instigated and finally became adopted.

BASIC PRINCIPLES USED IN THE DEVELOPMENT OF AN IN-PLACE TYPE VARIABLE-CUT SUGAR BEET TOPPER

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The development of a satisfactory in-place topper has been attempted by many individuals and by a few organized groups. In general, efforts have been confined to the production of a finished machine with little emphasis placed on the fundamental nature of the problem. This paper will describe an investigation of some of the principles common to all in-place toppers, and an effort to apply the results to the design of a finished machine.

In-place topping consists of two essential operations. First, a gauging device must place a cutting mechanism in position to remove the proper amount of crown material from each beet. Second, the cut must be made without excessive damage to the root.

DETERMINATION OF GAUGING REQUIREMENTS

The tare charts issued by the sugar beet processing companies may be considered implied recommendations of the proper location of the topping cut. Since these recommendations are based on the location of the lowest leaf scar, it is evident that any satisfactory gauging system must make use of some dimensional characteristic of a beet which is a function of its crown thickness.

Data were taken in a number of fields in Utah, Idaho, and California under a wide variety of soil and climate conditions in an effort to discover a correlation between diameter or height and crown thickness. All measurements of height were made from a plane midway between the level of the ground adjacent to the beets and the level at the base of the furrows.

Curves representing the averages of these data are shown in Figure 1. Curve (A) shows the relation between the beet height and the greatest beet diameter. Curve (B) shows the distance above ground level of the lowest leaf scar as a function of beet diameter. In each case, the data are well represented by a straight line passing through the origin.

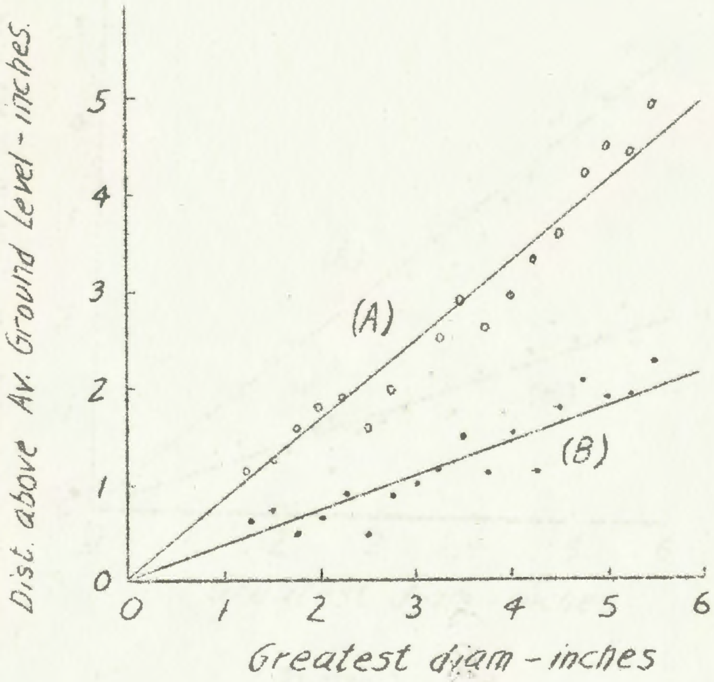

Figure 1

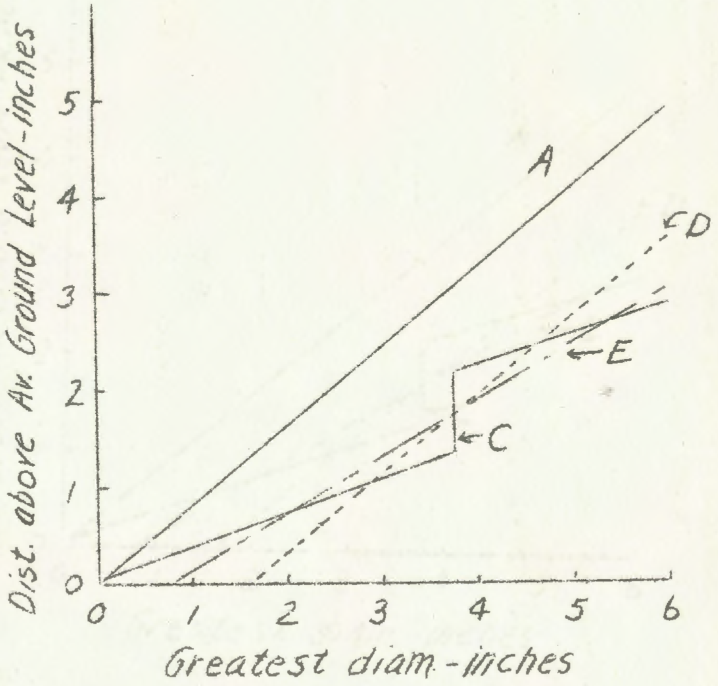

Figure 2

In the average case, the height of a beet is equal to 81 per cent of its greatest diameter, and the distance above ground level of its lowest leaf scar is 36 per cent of its greatest diameter. Since crown thickness is equal to beet height minus the height of the lowest leaf scar, it is equal to 45 per cent of the greatest diameter.

According to the average tare standards set up by the processing companies, it would be desirable to top each beet less than 3-3/4 inches in greatest diameter at the lowest leaf scar, and to top all larger beets 3/4 inches above the lowest leaf scar. This ideal topping performance is represented in Figure 2 by curve (C). This curve is the ideal locus of the topping knife for beets of different diameters.

Most experimental in-place toppers have utilized a finder which was designed to roll or slide over the tops of the beets, and a knife which was mounted a fixed distance below the finder. Evidently, such a device will remove a slice of uniform thickness from all beets, regardless of height or diameter. Since the knife and the finder rise and fall in unison, the distance of the knife above average ground level may be shown in Figure 2 as a straight line parallel to curve (A). The intercept of this performance line would vary as the machine was adjusted for different thicknesses of cut. Its estimated best position is represented by curve (D), Figure 2. Comparison with curve (C) shows that in a fixed-cut system, large beets would be topped too high and small beets would be topped too low.

The estimated best straight-line approximation of curve (C) is shown as curve (E), Figure 2. Physically, this represents a topping system in which the knife is raised 1 inch for each 1.4 inch rise of the finder. This has been called a variable-cut topping system. The thickness of the slice removed from each beet would be 0.45 inches plus 23% of the greatest beet diameter, or 0.45 inches plus 29% of the beet height. High topping of large beets and low topping of small beets would be eliminated.

The foregoing predictions of the relative performance of fixed-cut and variable-cut toppers have been substianted in field tests with machines of each type. Data have shown that topping losses and top tare in the fixed-cut system are from 50 per cent to 100 per cent greater than in the variable-cut systems.

In addition to satisfying accuracy requirements, a gauging device must be capable of adjusting itself to beets of different heights with sufficient rapidity to permit a reasonable harvesting speed. Consider the action of an in-place topper in the field. An appreciable amount of time is required for the finder to fall from the top of a high beet to ground level. Since the entire topping mechanism is progressing down row at the harvesting speed, an interval will follow each high beet during which a low beet cannot be topped. If the knife and finder are linked together, the finder cannot begin its descent until the knife has passed completely through the high beet. This causes a further increase in the skip distance. If the working parts fall through the effect of gravity alone, the skip distance will be approximately 9 inches at a harvesting speed of 2.5 m.p.h. The obvious remedy is to force the mechanism through spring action to fall as rapidly as necessary.

As the finder approaches a high beet, an opposite condition is encountered. A finite amount of time is required to raise the finder from ground level to the top of the beet. Unless a complicated relay system is used to elevate the topping mechanism, the beet must supply the raising force. Since the beet will sustain only a limited load before failure occurs, it is evident that the downward thrust on the finder must be small or the raising must be done slowly. If the former alternative is chosen, the skip distance following the beet is increased. If the latter is chosen, the skip distance preceding the beet is increased.

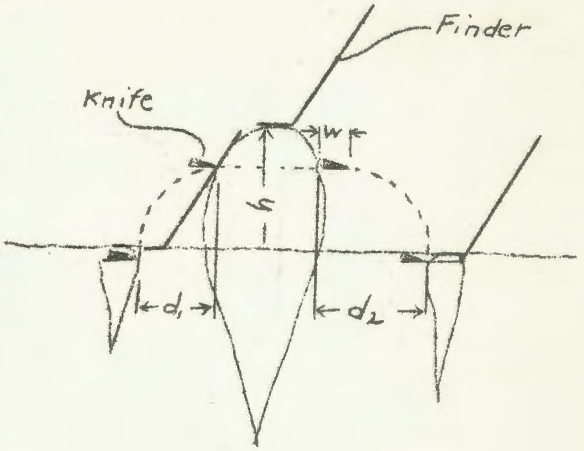

Fig. 3

Quantitative expressions describing these effects have been derived. It is found that: (refer to figure 3)

$$\frac{F_s}{W} = 1.603\, h \left(\frac{S}{d_2 - w}\right)^2 - 1 \qquad [1]$$

$$\frac{F_b}{W} = 1.603\, \frac{hS^2}{d_1^2} \left[1 + \left(\frac{d_1}{d_2 - w}\right)\right] \qquad [2]$$

where:
F_s = Spring thrust on finder (lbs.)
F_b = Force required to lift finder (lbs.)
W = Total effect dynamic weight of moving parts referred to finder (lbs.)
S = Harvesting speed (mph)
w = Effective knife width (in.)
h = Distance through which finder falls (in.)
d_1 = Skip distance preceding high beet (in.)
d_2 = Skip distance following high beet (in.)

In equations [1] and [2], h, d_1, d_2, and F_b may be regarded as field requirements whose values are subject only to limited manipulation by the machine designer. The following tentative values of these quantities have been derived from field tests and observations:

h = 6 inches (minimum)

$d_1 = d_2$ = 5 inches (maximum)

F_b = (60 lb. horizontal thrust (maximum)
)
(250 lb. vertical thrust (maximum)

The variables left within the control of the designer are W, w, S, and the direction in which the lifting thrust is applied to the beet. With the other quantities fixed, the permissible effective weight will vary inversely with the square of the harvesting speed. For example, if h, d_1, d_2, and F_b have the tentative values stated above and w is 1.5 inches:

$$W = \frac{214}{s^2}$$ (if the lifting force is applied vertically to the beet)

and

$$W = \frac{72.5}{s^2}$$ (if the lifting force is applied to the beet at an angle of 45°)

DETERMINATION OF CUTTING REQUIREMENTS

Most in-place toppers have used either a simple knife blade or a rotating disc to perform the cutting operation. The knife blade is light and inexpensive but has a tendency to break beets which can be eliminated only by the addition of a power-driven mechanism to support the crowns. The rotating disc cuts without breakage but is relatively heavy and requires a complicated power drive.

An oscillating knife blade has been developed in an attempt to combine the best features of the older systems. An effort has been made to correlate its performance characteristics with those of other cutting devices through laboratory tests and theoretical considerations.

The tests were made on samples 3-1/4 inches in diameter cut from beets of various diameters. A knife blade was ground to an included angle of 12° and passed through the samples at simulated harvesting speeds ranging from 1-1/2 to 3-1/2 miles per hour. Means were provided to oscillate the knife in a direction parallel to its edge at frequencies ranging from 0 to 50 cycles per second. Its stroke was adjustable from 1/4 to 3/4 inches.

The sample was so mounted as to be rigidly restrained in the harvesting direction, but free to oscillate laterally except for its own inertia. This is approximately the condition which exists in a field where the soil is light or moist. A small notch in the knife blade left a record on the cut surface of the effective lateral cutting stroke.

These formulas were found to agree with the laboratory data within the limits of experimental error.

The following conclusions may be drawn from the test data:

1. The minimum advisable frequency for an oscillating knife is 30 cycles per second.
2. The down-row thrust per unit of beet diameter must be less than 7.7 lbs. per inch if breakage is to be avoided.

DESIGN OF A FIELD TOPPER

If an oscillating knife is used in the cutting operation, the necessary periodic driving force may conveniently be obtained from the reaction of a rotating, eccentrically mounted weight. Since the power requirements are moderate, the driving torque may be applied to the rotating slug through a flexible shaft. This construction reduces the number of loaded bearing surfaces to a minimum and gives freedom of motion in all directions.

Formulas have been derived to facilitate the design of a system such as the one shown in Figure 4. If there are no springs which take part in the periodic motion:

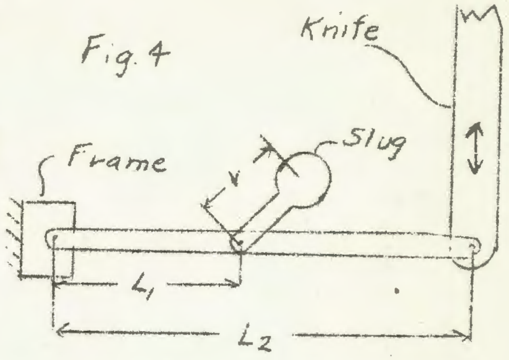
Fig. 4

$$r = 0.5 \; k \; s \left[\frac{1}{1 - \dfrac{s^2 f^3 W_1}{164500 \, P_{max}}} \right]$$

$$W_2 = \frac{W_1}{k^2} \left[\frac{164500 \, P_{max}}{s^2 f^3 W_1} - 1 \right]$$

where:

r = Distance from center of rotation to center of gravity of the slug (in.)
W_2 = Weight of rotating slug (lbs.)
k = L_1/L_2 (see Fig. 4)
s = Knife stroke (in.)
f = Frequency (cycles per second)
W_1 = Total effective dynamic weight of oscillating parts (excepting the slug) referred to the knife, (lbs.)
P_{max} = Maximum power which can be delivered by the knife by virtue of its oscillation (hp).

Any form of rotating slug having the values of r and W_2 indicated by the formulas will fulfill the requirements. The choice of any particular shape will depend on design convenience.

The equations show that as the maximum available cutting power is increased, r becomes smaller and W_2 becomes greater. It is desirable to use the lowest value of P_{max} which will result in a satisfactory shape of slug. In any practical design, it will be found that this value of P_{max} is greater than 0.5 hp which has been found to represent the maximum cutting requirements.

Many of the problems which arise in the design of a practical in-place topper are not subject to theoretical treatment. The solution of some of these "incidental" problems is more difficult than the mere satisfaction of the fundamental requirements. These difficulties may be broken down into three principal classes: interference with working parts, wide variations from nominal field conditions, and conflicts in design requirements.

Rank foliage, weeds, seed stalks, and dried petioles tend to hamper both gauging and cutting operations. Perhaps the most serious situation is one in which large beet tops in combination with any or all of the other items form a mat ahead of the finder and prevent the topping of low beets. In the experimental topper developed in connection with this project, this difficulty was overcome by the use of a narrow finder which is centered on each beet by an auxiliary mechanism. Some new problems which will involve further study have been introduced through the use of this device, but it has been found capable of threading its way through the rankest top growth.

The use of rolling coulters to sever the dried petioles and of a conveyor mechanism to carry the tops and weeds past the working parts has eliminated clogging in all cases except where a heavy growth of wild morning glory is present.

There is no standard practice in the raising of sugar beets. Row spacing, and planting, thinning, cultivating, and irrigating procedures vary with individual tastes and requirements. A machine may be made sufficiently flexible to permit its adjustment to the average conditions in any one field without undue complication. However, variations within that field present a serious problem.

Some of the more troublesome items are: variations in row spacing, crooked rows or furrows, off-row beets, burrows of varying depth, irrigation dams and ditches, leaning beets, beets in double or other multiple combinations, and off-type beets. All of these factors except the last are under the direct control of the farmer and may be held to reasonable limits. The percentage of off-type beets is small and may be subject to further reduction in the development of seed strains.

In the experimental machine, the effects of the first three items have been minimized through the use of a straight blade knife and a self-centering finder. The disc is sensitive to these conditions because of its relatively small radius of curvature.

The performance of a fixed cut topper is not influenced by variations in furrow depth since the thickness of cut is constant. In the variable cut system, lowering the wheels has the same effect on the thickness of cut as raising the finder. In sections of a field where furrows have been deeply cut by irrigation water, beets are topped too low. Even moderately high irrigation dams result in high topping of high beets and skipping of low ones. A suggested remedy would be to design a machine in which the topping mechanism could float with respect to the wheels and adjust itself to the level of the ground adjacent to the beets. The experimental machine was not built in this way.

Leaning beets and doubles present a serious problem in any system of in-place topping. The only apparent solution is to reduce their number by improved farming methods.

In the discussion of gauging requirements, a definite relationship was shown among the harvesting speed, the skip distances, the direction in which the lifting force is applied to the beet, and the permissible weight of the topping and gauging mechanism. When an attempt is made to design a topper to operate at speeds in excess of two miles per hour, it is found that the weight of the working parts must be made very low if skip distances are to be held to desirable limits. It is difficult to design such parts with the strength and rigidity necessary to fulfill field requirements.

In the experimental machine, the working parts were purposely designed to the lower limit of strength with a view to correcting structural weaknesses as they became apparent. Liberal use was made of heat-treated alloy steels and of the aluminum alloys. The resulting structure has been found to be surprisingly fieldworthy in the limited tests which have been conducted. It now appears that its development will be in the direction of better design, with only moderate increase of weight. The total effective dynamic weight of the gauging and cutting mechanism referred to the finder is less than 5 lbs.

Whereas field tests with the experimental topper have indicated the necessity of further refinements in operating details, the results have demonstrated that the application of fundamental theory to the design of a field machine is a promising method of attack.

The force required to draw the knife through the beet would evidently reach a maximum at the center of the sample, since the width would be a maximum at this point. Means were provided to record the component in the harvesting direction of this maximum cutting thrust.

When the knife was not in oscillation, it was found that the cutting thrust was approximately 60 lbs. and was nearly independent of harvesting speed. In most cases, the knife would cut through approximately two-thirds of the sample, at which point failure of the beet would occur on a 45° plane.

When the knife was oscillated at frequencies below 17 cycles per second, the beet was found to oscillate in unison with it, so that no effective cutting stroke was obtained. The cutting thrust was the same as with a non-oscillating knife. As the frequency was raised above 17 cycles per second the inertia effects in the sample attained such proportions that a small effective stroke appeared. The effective stroke increased with frequency until, at 30 cycles per second, it was equal to the knife stroke. It was unchanged with further increase in frequcney

The cutting thrust was measured for a variety of frequencies, strokes, and harvesting speeds. It was found to increase with harvesting speed. At frequencies above 30 cycles per second it was independent of stroke and frequency but was inversely related to their product. Breakage of the samples became less serious as the cutting thrust was reduced, and did not occur at values of thrust below 25 lbs. Thrusts of 25 lbs. occurred when the ratio of the product of the stroke and frequency to the harvesting speed was 0.7.

To check and correlate the data, the following expressions for the cutting thrust were derived on theoretical grounds:

$$F = K \quad \text{(for non-oscillating knife)}$$

$$F = \frac{K}{1 + \left(\frac{v_p}{v_h}\right)^2} \quad \text{(for rotating disc)}$$

$$F = \frac{K}{\sqrt{1 + \left(\frac{v_m}{v_h}\right)^2}} \quad \text{(for oscillating knife)}$$

where:

F = Down-row thrust per unit beet diameter $\left(\frac{\text{lb.}}{\text{in.}}\right)$

K = A constant dependent on knife sharpness and beet toughness $\left(\frac{\text{lb.}}{\text{in.}}\right)$

= 18.5 lb/in. in these tests.

v_p = Peripheral velocity of disc cutter.

v_h = Harvesting speed.

v_m = Maximum value of lateral velocity of oscillating knife.

= π x stroke x frequency.

v_p, v_h, and v_m are in the same units.