IMPROVED FURROW IRRIGATION EFFICIENCY THROUGH CONTROLLED SOIL COMPACTION

by

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September 24, 1985

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Research Project Technical
Completion Report (USGS G-943, Project No. 06)

Prepared for:
U.S. Department of the Interior
U.S. Geological Survey

The research on which this report is based was financed in part by the United States Department of the Interior as authorized by the Water Research and Development Act of 1978 (P.L. 95-467).

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INTRODUCTION

A significant portion of the surface irrigated cropland in the western United States is located in alluvial valleys. For example, in Wyoming, an estimated 350,000 ha of the total of 730,000 ha of surface irrigated land is in alluvial valleys, and there are 21,000,000 ha of surface irrigated lands in the 17 western states (Anon. 1982). Soils in these valleys are typically sandy, and have very high water infiltration rates. The problem of high infiltration rates is particularly severe when minimum tillage practices are used in these soils.

Furrows are normally formed using a furrow opener. This device leaves the furrow surface relatively loose and rough. These factors contribute to high infiltration and to erosion and transport of sediments both within the field and with tail water.

A compaction roller will firm and smooth the furrow wall and bottom. Compaction reduces the infiltration rate, and water advances more rapidly across the field because of the smooth furrow surface. Water intake, thus, is more nearly uniform along the entire length of the furrow. Less total water is required and water is applied more uniformly. With appropriate compaction of irrigation furrows, crop production should be enhanced with less water and with reduced water degradation.

Although not directly addressed in current research, a significant possibility exists for savings of plant nutrients, particularly nitrogen. Assuming that 100mm of excess water becomes deep seepage on the 350,000 ha of surface irrigated area in the alluvial valleys of Wyoming and using values reported by

Duke (1978), between 6,700 and 21,000 metric tons of nitrogen are leached to ground waters from alluvial valleys each year in the State of Wyoming. It should be noted that 100mm of deep percolation is a very conservative estimate. Additional benefits of furrow compaction include improved irrigation tail water quality because of reduced erosion and the corresponding reduction in sediments transported to tail water collection facilities of streams.

Compaction of furrow walls provides several direct benefits to irrigation. First, compaction decreases the rate of infiltration of water from the furrow to the surrounding soil. Khalid and Smith (1978) reported approximately 40 percent decrease in the rate of infiltration from compacted furrows in sandy soil.

Soothing furrow walls significantly decreases the resistance to flow of water in furrows. Borrelli, et al. (1982) reported that water advanced approximately 40 percent faster in compacted furrows. The combined effect of reducing the infiltration rate and increasing the rate of water flow in the furrow is to provide a nearly equal opportunity time along the length of the furrow. This means that the uniformity of irrigation and the irrigation efficiency would be increased. Based on results reported by Borrelli (1982), the efficiency of surface irrigation with compacted furrows may be nearly equal to the efficiency of sprinkler irrigation.

As indicated above, Borrelli (1982) and Khalid and Smith (1978) used compaction to control furrow irrigation. However, neither of these investigations provided an overall analysis of the potential benefits of furrow compaction. Further, although both of these investigations produce considerable information required for the design of the compaction system, neither research effort evaluated the compaction system.

The current research was conducted during the 1985 growing season at the University of Wyoming, Powell Research and Extension Center. At Powell, the experiments were conducted on conventionally tilled dry beans with a furrow length of 320m. Water was delivered using 50.8mm siphon tubes. The soil at Powell was classified as a clay loam, but its irrigation characteristics resembled those of a coarse sand. The soil formed very coarse granular aggregates and thus, had high water intake rate and required an initial flow rate in excess of 90 l/min to move water down the furrow at a reasonable rate. The maximum flow rate for non-erosive flow should have been less than 76 l/min (Marr, 1967).

OBJECTIVES

1. To evaluate the hydraulic, infiltration and erosion stability of compacted triangular and parabolic furrows. The evaluation will be based on irrigation efficiency, uniformity and sediment transport within and from the field.

2. To develop a method for predicting the required furrow compaction effort to achieve desired hydraulic and infiltration characteristics.

3. To redesign the experimental compaction machine to accommodate parabolic shaped wheels in addition to the existing triangular shaped wheels, and to evaluate performance of the machine in the field with various levels of compaction effort.

LITERATURE REVIEW

Compaction is defined as the increase in soil bulk density as air and/or water is forced out or redistributed among soil pore spaces (Finkel, 1982). Compaction will result in a decreased permeability of the soil to water and/or in a decreased permeability of the soil to water and/or air (Bailey, 1968). Several factors can influence soil compaction in an interrelated fashion. Among these are soil moisture, soil type, and method of compaction.

Several types of compaction equipment are available today. These can be grouped into four classes:

1. Rollers (pneumatic, smooth wheeled and sheep's foot)
2. Rammers (internal combustion and pneumatic)
3. Sleds (torpedo and flat)
4. Vibrators (rollers or plates)

Khalid and Smith (1978) used a rammer-type compactor successfully in sandy loam to produce smooth furrows, but found speed of the unit a serious limiting factor. Sleds are used in certain areas of agriculture, but tend not to leave a smooth surface in cohesive soils. Generally, vibratory rollers are not effective in cohesive soils and require a large number of passes at typical travel speeds to obtain a given relative compactness (Lewis, 1961).

Of the above roller types, the sheep's foot design does not leave a smooth surface, and must be disregarded. The pneumatic tire can be used in both cohesive and cohesionless soils, but it has a serious drawback with tire flexing. This will cause uneven loading and non-uniformity in furrow shape.

The smooth-wheeled roller seems to be the best tradeoff between speed and compaction ability. Bakhsh (1978) showed that an increase of 110% in forward speed only increased the infiltration rate by 15% for a smooth-wheeled compactor. The wheel type also requires less total power when compared to the impact rammer (Khalid and Smith, 1978).

Three basic shapes can be used for the furrow cross section: triangular, trapezoidal and parabolic. The triangular shape is the easiest to manufacture, and is typical of the shape made by most furrow openers. Parabolic has the advantage of being the most stable (Chow, 1959) and should have different advance and infiltration characteristics due to the different wetted perimeter and hydraulic radius. The trapezoidal is basically a compromise between the triangular and parabolic, and thus, was not considered for this research.

Infiltration rate along with bulk density and resistance to penetration have successfully been used to determine the degree of compaction (Schmidt, 1963). Earlier research in Idaho (Yarris, 1982) and Colorado (Khalid and Smith, 1978) demonstrated a definite decrease in infiltration rates with a corresponding increase in compaction weight.

Infiltration can be defined as the process in which the water from the soil surface flows down into the soil. It depends on many interrelated factors which include soil type, soil texture, soil structure, soil moisture, soil temperature, ion presence, water temperature, depth of water applied and the method of application.

The infiltration process replenishes available water and is therefore critical for plant growth (Nielson, et al. 1967).

Of the many methods available to measure infiltration, the blocked-furrow test was used in this research. Other tests that have been used in the past include cylinder infiltration, inflow-outflow measurements and the volume balance based on advance rates. The cylinder-infiltration test is very similar to the blocked furrow test. While both use fixed area, they do not account for an average over the furrow length.

Davis and Fry (1963) and Smerdon and Glass (1965) claimed that the volume-balance method was the most accurate, since it takes into account an entire length of furrow. However, Karmeli, et al. (1978) found a substantial difference from the above and encouraged blocked-furrow or cylinder-infiltration tests.

In this research, blocked-furrow tests were run using a one-meter section of furrow isolated by two aluminum plates. The flow of water was maintained at a constant head, a procedure initiated by Bondurant (1957) and Shull (1961). One major disadvantage of this approach is that it only involves a small section of the furrow length and the water has no horizontal velocity. Therefore, the soil structure is not the same as compared to when it is exposed to water.

Penetrometers are a relatively inexpensive and extremely quick method of obtaining soil compaction data. Force versus depth measurements can easily be taken to determine both the degree and the relative depth of compaction.

Cone index is defined as the average vertical force required to drive a cone penetrometer slowly to a certain depth (Finkel, 1982). It can be expressed in Newton's per square meter or in pounds per square inch, but is usually treated as a dimensionless number (Chan and Hendrick, 1968). Two sizes of cones are expressed as being standard (ASAE standard S313.3): 20.27 millimeters and 12.83 millimeters of projected surface area. All penetrometer readings obtained in this research were taken using the 12.83 millimeter cone on the two-hand penetrometer.

Chan and Hendrick (1968) attempted to relate penetrometer soil cone index values to soil hydraulic conductivity. Other factors that influence soil cone index readings are soil moisture, soil texture, depth of reading and soil bulk density.

In general, it has been found (Khalid, 1978) that both cone index readings and soil strength increase as:

1. silt and clay content increase
2. water content decreases
3. depth increases
4. bulk density increases

In Wyoming, soil losses on slopes of only 0.5 percent have been measured as high as 1 ton/acre/irrigation for furrow-type irrigations (Michel, et al., 1983). This must be coupled with the fact that topsoil can normally be generated at a rate of less than 1 ton/acre/year under optimum conditions. Some fields have been observed to lose soil at a rate of 40/tons/acre/year (Michels et al., 1983).

Along with the actual soil particle loss, nutrients and pesticide particles are also lost. Duke et al. (1978) claim a loss of 36 kg/ha of nitrogen with each centimeter of deep percolation. In addition, erosion can cause problems for fish and damage streams and reservoirs.

Five major factors affect the rate of advance down a furrow: flow rate, slope, resistance to flow, infiltration and shape. By use of the machine developed in this research, one can partially control the last three parameters.

The flow rate can be constant or vary, but it should be controllable by the irrigator throughout the irrigation. The slope can be changed in elevation over a distance while in fact, it is not constant. This leaves the last three parameters which can affect advance.

The resistance to flow can be taken as having two separate factors: the soil surface and the vegetative growth. Since conventional tillage and furrow openers are used to open and clear the furrow, effects of the vegetative growth may be disregarded. Therefore, the analysis can be simplified to a single factor for roughness, which is usually indicated by Manning's coefficient "n" (Hart, 1975).

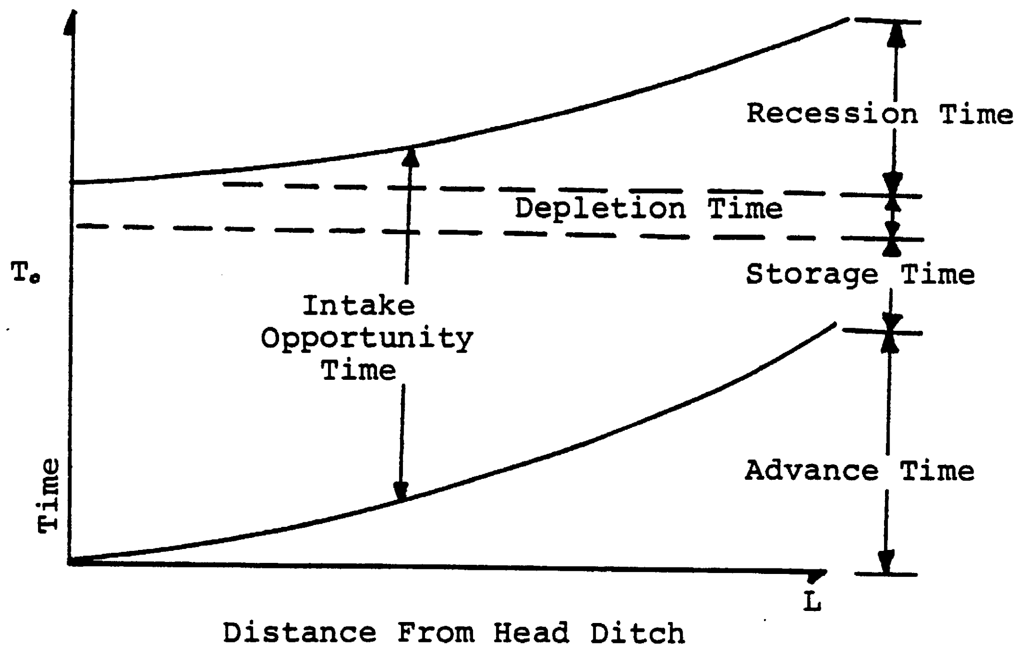
The infiltration rate is controlled by many factors including soil structure, soil type, temperature, texture, and moisture. It also varies with time and location in the length of the furrow.

The shape of the furrow also has to be considered, as both the wetted perimeter and volume of flow are affected by the shape. Most case studies have used a wide, shallow channel to simplify the problem. This allows the hydraulic radius to be represented as the depth of flow and infiltration in a downward direction only (Hart, 1975). In the case of a furrow, the problem becomes much more complicated, because the infiltration function is two dimensional rather than a simple downward flow.

Surface irrigation involves the non-uniform flow of water over a porous bed. The process involves applying water at the upper end of the field and allowing the water to flow down the slope. Analysis of the process usually involves the water advance over the length of the field, buildup of impounded surface storage, depletion of surface-stored water and recession of water from the furrow surface. These are illustrated in Figure 1 along with the intake opportunity time, which is the time available for water to infiltrate the soil.

Measurement of the times and distances involved in Figure 1, along with the inflow and outflow rates, normally allows evaluation of the efficiency and uniformity of the irrigation. Of the several irrigation-efficiency measures, the water-application efficiency is the most useful for evaluating in-field performance. The water-application efficiency is defined as that portion of the water available to the field that is required by the crop. The water required by the crop includes the consumptive use and the water required to maintain a suitable soil balance (leaching requirement).

The degree of uniformity of water application is determined by the uniformity of the intake-opportunity time and the variation of the soil-water intake (infiltration), which are characteristic along the field. If the intake characteristics are relatively constant, one can achieve a high degree of uniformity with a constant intake-opportunity time.



Graphic Summary of an Ideal Irrigation

Figure 1.

Efficiency and uniformity are often at opposing ends of the spectrum for irrigation evaluation. For example, applying water for very short time periods may be highly efficient, but there may be insufficient water applied to the tail end of the field. This would cause the efficiency to be high, but the uniformity would be poor because a portion of the crop might not receive any water. Alternatively, one can achieve good uniformity by applying a large amount of water for a long period of time. In this case, the intake-opportunity time will be approximately equal over the length of the furrow, but adverse effects may include excess tailwater runoff, erosion, water logging and loss of soil nutrients. Therefore, the uniformity will be good, but the water-application efficiency will be correspondingly poor.

In general, a rapid advance rate followed by a reduced flow when water reaches the far end of the field, will produce an efficient, uniform irrigation. Therefore, decreasing the advance time by compaction of the furrow and furrow-wall smoothing should be beneficial in improving furrow-irrigation performance.

Trends of benefits obtained by compacting irrigation furrows can be predicted using Hall's (1956) solution of the Lewis-Milne (1938) equation. Although this analysis applies to border irrigation, trends should also be applicable to furrow irrigation.

The Lewis-Milne equation involves Manning's equation (Hansen, et al. 1979) and the Kostiakov-Lewis infiltration function, $z = Kt^a$, where z is the depth of water infiltrated, t is time and K and a are constants. Decreasing the exponent, a, by compacting the soil, would decrease the water infiltrated and would thus increase the advance rate. Hydraulic resistance to advance down the channel is reflected in Manning's coefficient, n. In Manning's equation, compacting and smoothing the channel would decrease hydraulic resistance (reduce n) and would increase the advance rate. From this analysis, one can observe the following:

1. Compaction is more beneficial in longer furrows.
2. Controlling infiltration (reducing a) is more important than reducing roughness (reducing n) of the furrow.
3. As infiltration becomes high, advance is relatively independent of n. Also, advance becomes very slow and essentially ceases at relatively short distances for high infiltration rates.

Working in heavy clay soils, Flocker, et al. (1959) proved that compaction may be beneficial for germination of tomatoes. However, soil compacted beyond a certain density seriously affected germination and plant growth. The compacted soil also lengthened the time of emergence for the tomato plants.

Taylor and Gardner (1963) stated that soil strength, rather than bulk density, controlled root penetration of cotton seedlings in fine sandy loam.

In a study of compacted plots of oats, Bourget, et al. (1961) found that uncompacted areas gave better yields than compacted areas. A check of yields of alfalfa and other grass crops did not indicate a wide margin of difference, yet favored uncompacted soil for plant growth.

Henry and McKinnen (1967) concluded that root growth was retarded in the compacted zone, but top growth was not affected by the compaction.

MACHINE DESIGN AND OPERATION

The wheel type furrow compactor is shown diagramatically in Figure 2 and in field operation in Figure 3. The machine consists of five basic parts; the opener, the packer wheel, the tool bar, the tract eliminator and the frame.

The non-compacted furrow opener was constructed of mild steel and was made to open a 110 degree inclusive furrow. The design allowed minor adjustment of the angle through the attachment to the shank. For the compacted

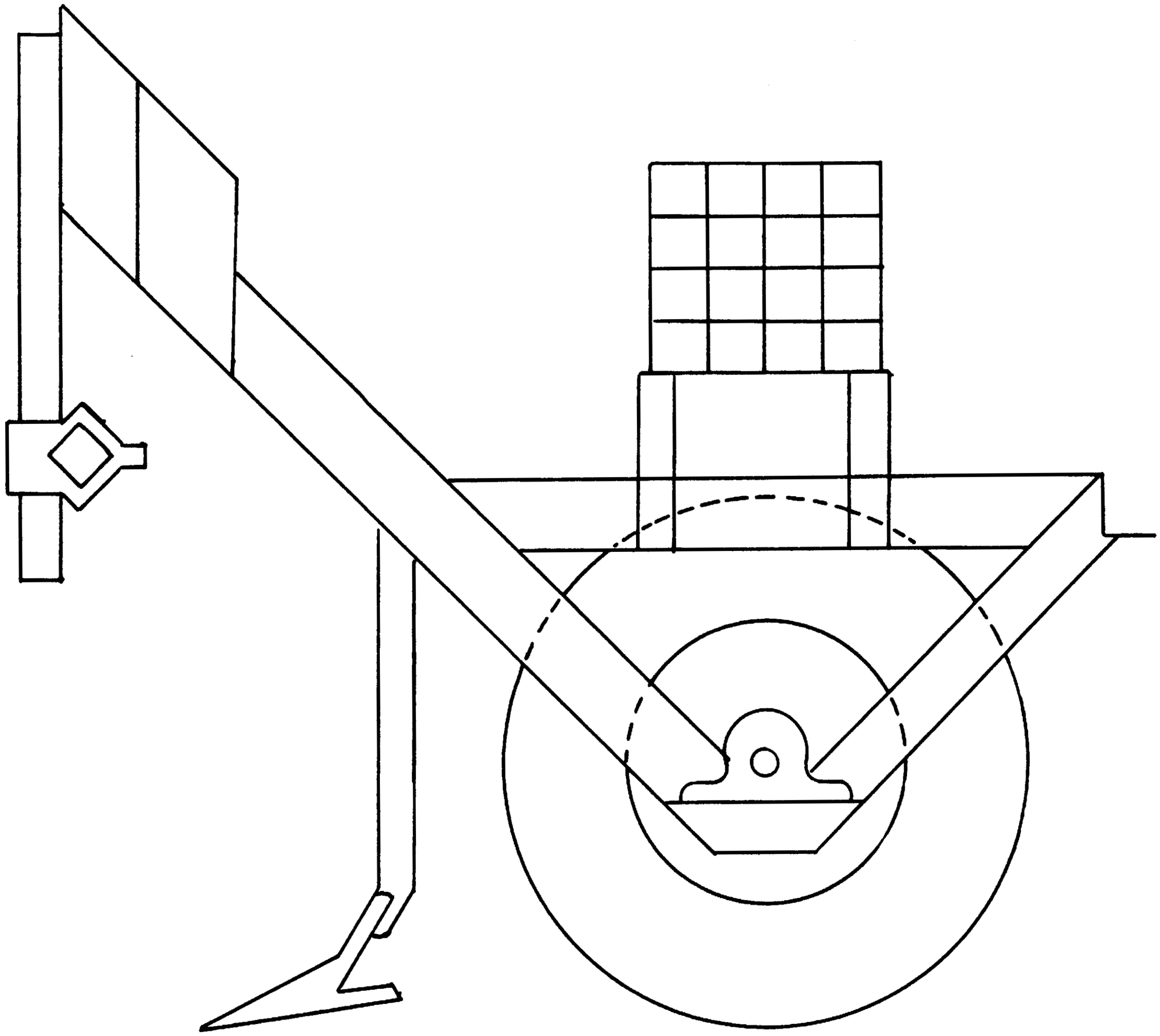


Figure 2a. Furrow packer diagram.

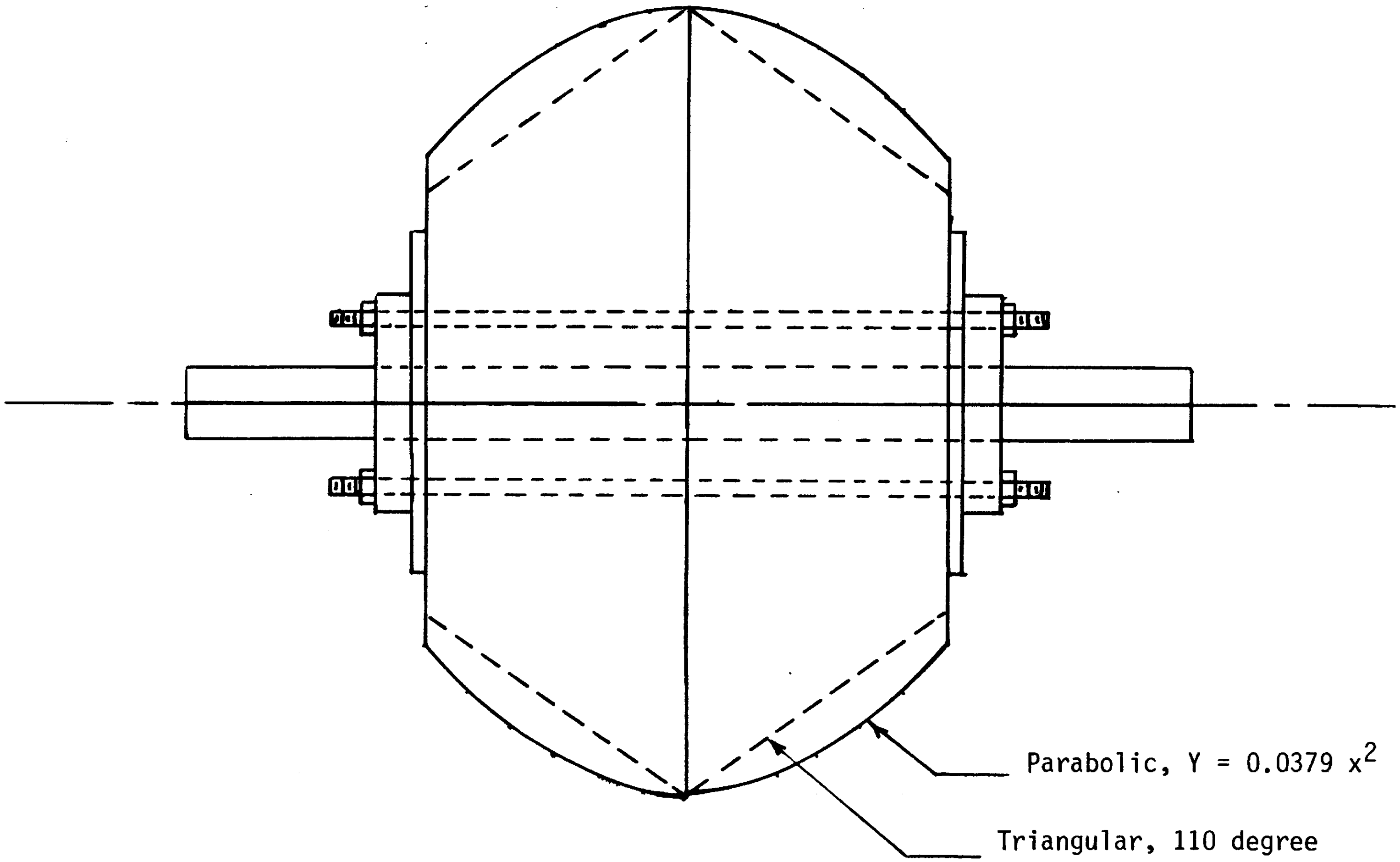


Figure 2b. Packer wheels.

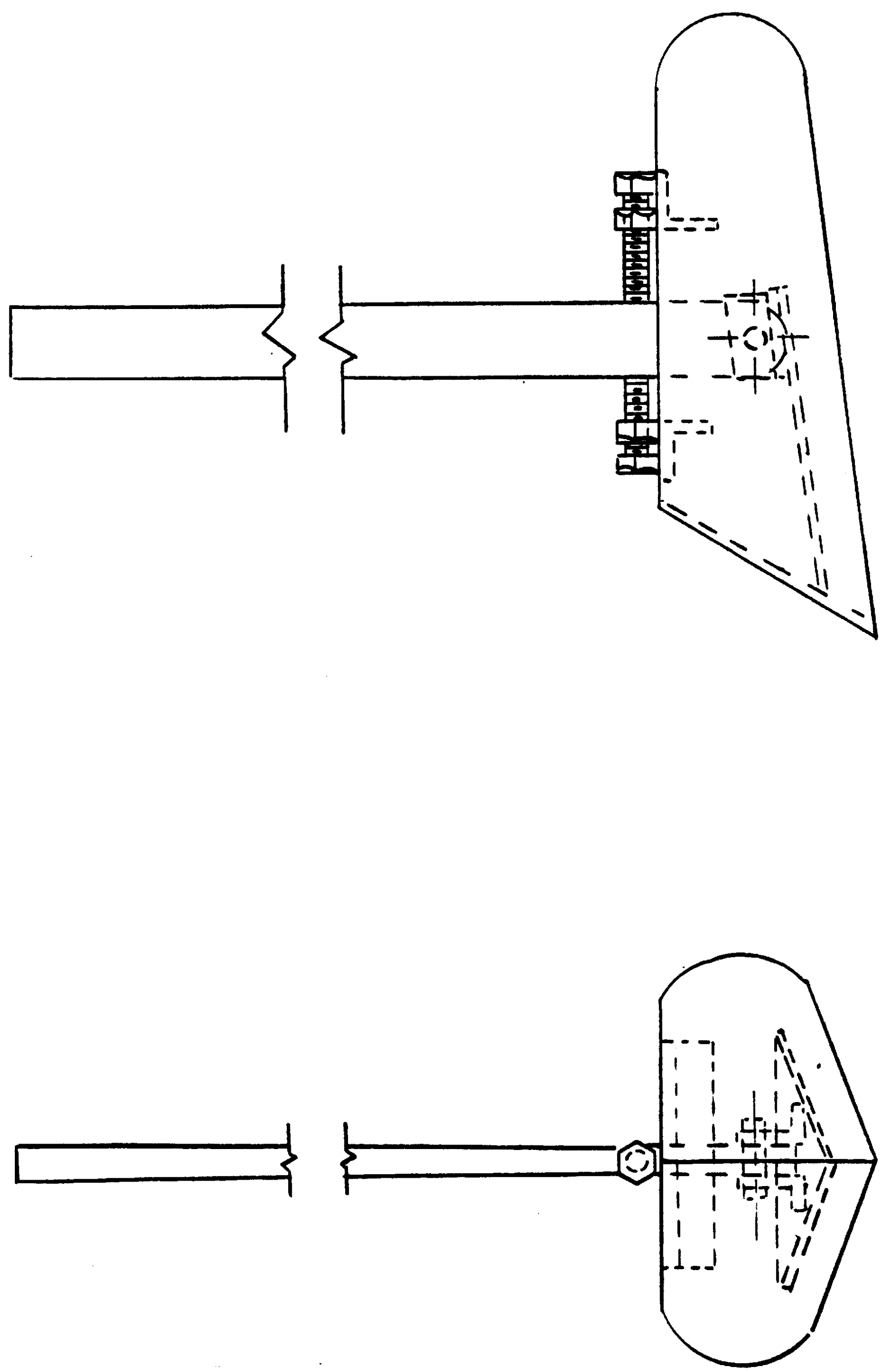


Figure 2c. Conventional Furrow Opener

Figure 3. Furrow packer in field operation.

furrows, a wide cultivator sweep was used to open the furrow. This prevented clods and debris from falling into the furrow behind the compaction wheel. The cultivator shank was mounted to the frame in front of the packer wheel so the wheel served as a depth guide. The vertical height of the opener could also be adjusted relative to the packer wheel.

The packer wheel was constructed of laminated 25.4mm nominal (19mm actual) pine to form the shape shown in Figure 1. Two wheel shapes were fabricated; triangular and trapezoidal. The triangular shape was fabricated with an inclusive angle of 110 degrees. The shape of the parabolic was $y = 0.0379x^2$ where y is the radial distance change and x is position along the axis of rotation. This equation was selected based on a field survey of theoretical analysis of furrow stability. After each wheel was laminated and shaped, it was covered with reinforced fiberglass and given a smooth finish. Two steel plates were attached to the sides and connected by long threaded studs.

Two flush mounted bearings were attached to the steel plate. The 25.4mm diameter axle was put in place and held using locking collars. The axle was then attached to the frame using pillow block bearings. Both sets of bearings were of the roller bearing type, with grease fittings and locking collars.

The toolbar was a standard 57mm diamond toolbar with an A-frame attached to allow hook up to the tractor three point hitch.

The track eliminators were used on the tractor wheel rows to eliminate compaction from the tractor wheels. Each rear wheel was followed by three shanks with sheeps foot, cultivators. By running these at 40mm depth, surface effects of the tractor were removed, but effects of deeper wheel compaction remained.

The frame was made of mild steel angle, flat stock and solid bar. With the exception of the four bar linkage, the entire assembly was welded. The four bar linkage was designed to allow 75mm of vertical travel each way from center height. Weights were fabricated bar stock and weighed approximately 5kg each. Each frame could hold 26 weights or an additional 80 kg of weight. The base weight of the frame with the opener and wheel attached was 70 kg. The weights were placed so the vertical force component on the wheel was equal to the weight added.

The entire frame assembly was made to ride on the wheel rather than a guide wheel. This led to more accurate depth of compaction and the weight aided in the compaction. The machine was adjusted to allow the toolbar to ride as low to the ground as possible. This allowed the four bar linkage to ride approximately horizontal which, in turn, allowed full vertical movement of the packer wheel relative to the tool bar.

Initial depth settings were obtained by placing the tractor and compactor on a level surface and lowering the tool bar. After loosening all clamps, the tool bar was lowered until the four bar linkages were approximately horizontal. All the furrow opener clamps were then tightened. The tool bar was then raised approximately 80mm and the track eliminators were tightened in this position. After tightening all clamps, the machine was ready for the field.

Once adjusted, weights could be added or subtracted without further adjustment to the packer wheel toolbar height. The machine could be easily transported to the field using the tractor three point hitch. In the field, the tractor was lined up with the rows, the three point hitch was lowered and the tractor proceeded down the field. The opener was run approximately 70-100mm below the soil surface. This pushed the soil out of the way and allowed the wheel to follow and compact the furrow surface. At the end of the field, the packer was lifted and the tractor was positioned for the return on the next five rows.

TEST EQUIPMENT AND PROCEDURES

The furrow packing machine was used with a John Deere 630 tractor, having a rated power output of 36 kilowatts. Tractor power was not a problem, but lift capacity (ability to raise the implement) was marginal without additional front end weights.

The depth of compaction was varied by adjusting the vertical position of the furrow opener relative to the compaction wheel (Figure 2) and by applying weights to the wheel. Each furrow assembly "floated" relative to the tractor three point hitch, through the parallel linkage attachment. This design allowed some leveling action by the opener, because the final furrow depth was controlled by the trailing compaction wheel.

Weight for compaction was added by placing 5kg weights in sets of four over the compacting wheel. This led to testing of three compaction levels; no added weight, 40kg of added weight, and 80kg of added weight. A control furrow was also made using only a furrow opener in the center row of the furrow compaction machine. During the experiment, three sets of data were obtained, those being; no compaction, compaction with half the added weight, and full weight compaction. Data were also collected in wheel furrows, in which the tractor wheels traveled versus furrows in which they did not.

The field was laid out (Figure 4, 5, 6, and 7), using random number generation with compaction level as the variable. During the initial layout, the field was surveyed at 25m intervals to determine slope, and irrigation advance station intervals were established at 80m intervals.

Infiltration was measured using blocked furrow tests 1m in length. A constant head tank, was used to measure the volume infiltrated. The blocked furrow tests were conducted on the day preceding irrigation. Geometric differences between triangular and parabolic furrows were accounted for by adjusting the depth of water in the infiltration test.

DISTANCE: 0 m. — 160 m. — 320 m.

HEAD DITCH

ROW	ROW TYPE
1	TNFW
2	PWFW
3	C
4	TWFW
5	PNFW
6	PNFW
7	TWFW
8	C
9	PWFW
10	TNFW
11	TNFW
12	PWFW
13	C
14	TWFW
15	PNFW
16	PNFW
17	TWFW
18	C
19	PWFW
20	TNFW
21	TNHW
22	PWHW
23	C
24	TWHW
25	PNHW
26	PNHW
27	TWHW
28	C
29	PWHW
30	TNHW
31	TNHW
32	PWHW
33	C
34	TWHW
35	PNHW
36	PNHW
37	TWHW
38	C
39	PWHW
40	TNHW

Legend: TNFW = Triangular shape, nonwheel row, full weight
PNFW = Parabolic shape, nonwheel row, full weight
P = Parabolic shape, T = Triangular shape
N = Nonwheel row, W = Wheel row, C = Check row
FW = Full Weight, HW = Half weight

Figure 4. Field Layout, Powell, Wyoming
Irrigation #1, June 13, 1985

DISTANCE: 0 m. — 160 m. — 320 m.

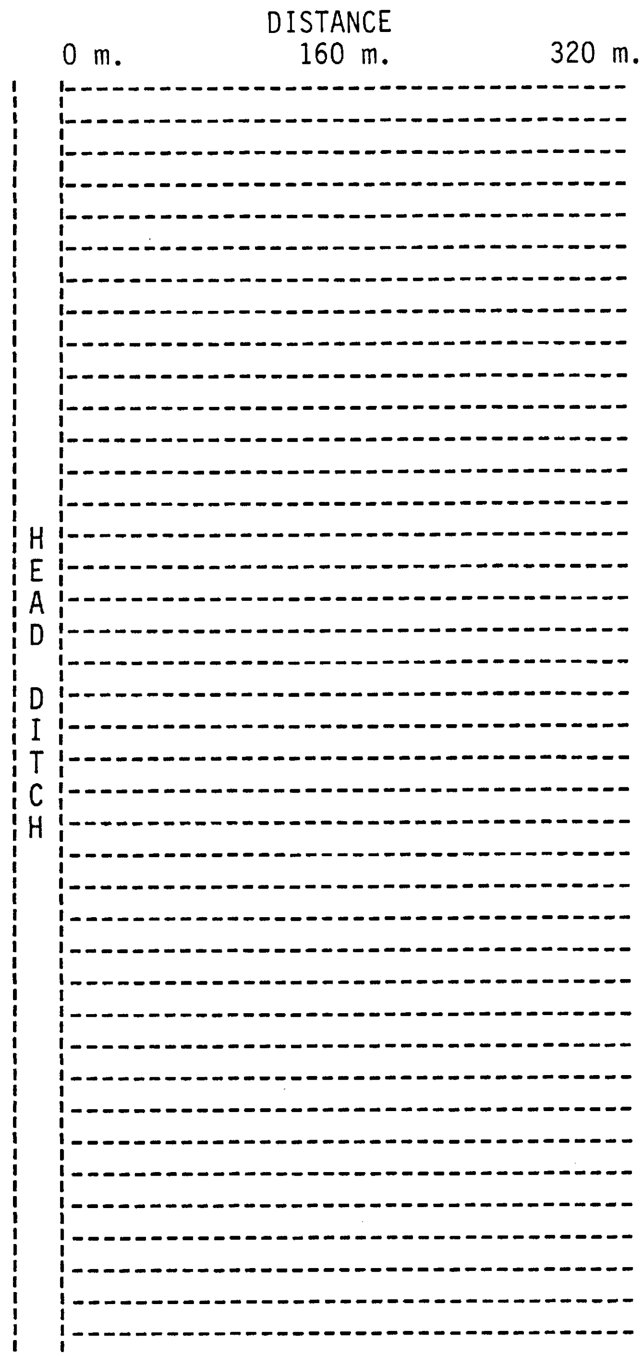
HEAD DITCH

ROW	ROW TYPE
1	TNFW
2	PWFW
3	C
4	TWFW
5	PNFW
6	TNHW
7	PWHW
8	C
9	TWHW
10	PNHW
11	TNHW
12	PWHW
13	C
14	TWHW
15	PNHW
16	TNFW
17	PWFW
18	C
19	TWFW
20	PNFW
21	TNFW
22	PWFW
23	C
24	TWFW
25	PNFW
26	TNFW
27	PWFW
28	C
29	TWFW
30	PNFW
31	TNHW
32	PWHW
33	C
34	TWHW
35	PNHW
36	TNHW
37	PWHW
38	C
39	TWHW
40	PNHW

Legend: TNFW = Triangular shape, nonwheel row, full weight
PNFW = Parabolic shape, nonwheel row, full weight
P = Parabolic shape, T = Triangular shape
N = Nonwheel row, W = Wheel row, C = Check row
FW = Full Weight, HW = Half weight

Figure 5. Field Layout, Powell, Wyoming
Irrigation #2, July 08, 1985

ROW	ROW TYPE
1	TNFW
2	PWFW
3	C
4	TWFW
5	PNFW
6	TNHW
7	PWHW
8	C
9	TWHW
10	PNHW
11	PNHW
12	TWHW
13	C
14	PWHW
15	TNHW
16	TNHW
17	PWHW
18	C
19	TWHW
20	PNHW
21	PNFW
22	TWFW
23	C
24	PWFW
25	TNFW
26	TNFW
27	PWFW
28	C
29	TWFW
30	PNFW
31	PNHW
32	TWHW
33	C
34	PWHW
35	TNHW
36	PNFW
37	TWFW
38	C
39	PWFW
40	TNFW



Legend: TNFW = Triangular shape, nonwheel row, full weight
PNFW = Parabolic shape, nonwheel row, full weight
P = Parabolic shape, T = Triangular shape
N = Nonwheel row, W = Wheel row, C = Check row
FW = Full Weight, HW = Half weight

Figure 6. Field Layout, Powell, Wyoming
Irrigation #3, July 23, 1985

ROW	ROW TYPE
1	PNFW
2	TWFW
3	C
4	PWFW
5	TNFW
6	TNHW
7	PWHW
8	C
9	TWHW
10	PNHW
11	PNHW
12	TWHW
13	C
14	PWHW
15	TNHW
16	TNFW
17	PWFW
18	C
19	TWFW
20	PNFW
21	PNFW
22	TWFW
23	C
24	PWFW
25	TNFW
26	TNHW
27	PWHW
28	C
29	TWHW
30	PNHW
31	TNFW
32	PWFW
33	C
34	TWFW
35	PNFW
36	PNHW
37	TWHW
38	C
39	PWHW
40	TNHW

HEAD DITCH

DISTANCE: 0 m. 160 m. 320 m.

Legend: TNFW = Triangular shape, nonwheel row, full weight
PNFW = Parabolic shape, nonwheel row, full weight
P = Parabolic shape, T = Triangular shape
N = Nonwheel row, W = Wheel row, C = Check row
FW = Full Weight, HW = Half weight

Figure 7. Field Layout, Powell, Wyoming
Irrigation #4, August 13, 1985

Water content samples were taken at the soil surface. These readings were taken along the length of the field and averaged.

Recession data were measured by recording the times at which flow stopped at the head of the furrow, each interval station along the furrow and tail of the furrow. Based on these measurements, the recession curves were established. It should be noted that recession data were very difficult to obtain because of non-uniformities in the field, furrows and variations in the soil-water intake function. Only one set of recession data was obtained due to the relatively short recession time for the field.

On the first set of measurements, trapezoidal flumes were used to measure furrow flows. Observations of flows from the siphon tubes with the flumes indicating nearly identical flows indicated that there were serious problems with the flumes. The expansive and unstable nature of the soil contributed to the problem, and it was impossible to maintain the flumes in position. For this reason, a rack (Figure 8) was constructed on the ditch bank which enabled positioning and holding of the siphon tubes so the head ditch essentially became a constant head tank. Siphon tubes were calibrated for flow at various water elevations and the calibration was used to determine all flows in subsequent tests. This method was very successful in maintaining constant flows in the tubes and furrows.

Furrow flow rates were maintained at levels in excess of 90 l/min for all tests. This relatively high rate was required in order to have the water reach the end of the field in a reasonable time period. The maximum non-erosive flow for this soil type and the 0.5% slope was 76 l/min (Marr, 1967).

Flumes were set a few meters beyond final stakes in the field to obtain sediment samples from the furrow. Flows indicated in the flumes were of questionable value, and thus, were not used in the analysis of data. Sediment

Figure 8. Constant head rack for siphon tubes.

samples were obtained to indicate steady state sediment losses and to obtain histograms of sediment losses from the furrows.

Sediment concentrations were determined by filtering the sample trough, a 9cm Buchner filter with Whatman 44 filter paper. The filtered sample was oven dried to determine actual dry soil weight.

Soil penetration resistance measurements were obtained, the bottom of the furrows using a Soiltest EL516-010 hand held penetrometer modified for use with the ASAE Standard (ASAE, 1982) cone. Locations were selected randomly along the rows.

PLATE COMPACTION PROCEDURE AND RESULTS

The plate compaction test was developed to model the compaction energy of a smooth roller. By using moisture-density relationships and the required energy to compact the soil to a desired dry density, a set of curves may be generated for a specific soil type (see Figure 9).

The equipment required to perform a plate compaction test includes a compression machine, CBR compaction mold, proving ring fitted with a dial gage, plunger, pointer and scale, soil oven, soil moisture cups, small tub and a balance. The test equipment is shown in Figure 10.

Soil preparation must be done under highly controlled conditions. First, a desired dry density for the soil must be selected. This is done by adding temperature stabilized soil to a small tub, until the desired mass was obtained to produce the desired dry density in the 2000 cubic centimeter CBR compaction mold. The recommended oven temperature for stabilizing was about 30°C. Since the moisture content of the temperature stabilized soil can be estimated, the volume of water required to produce a given moisture content during compaction can be calculated. After measuring the water to be added to the sample, it was mixed thoroughly in the tub of temperature stabilized soil

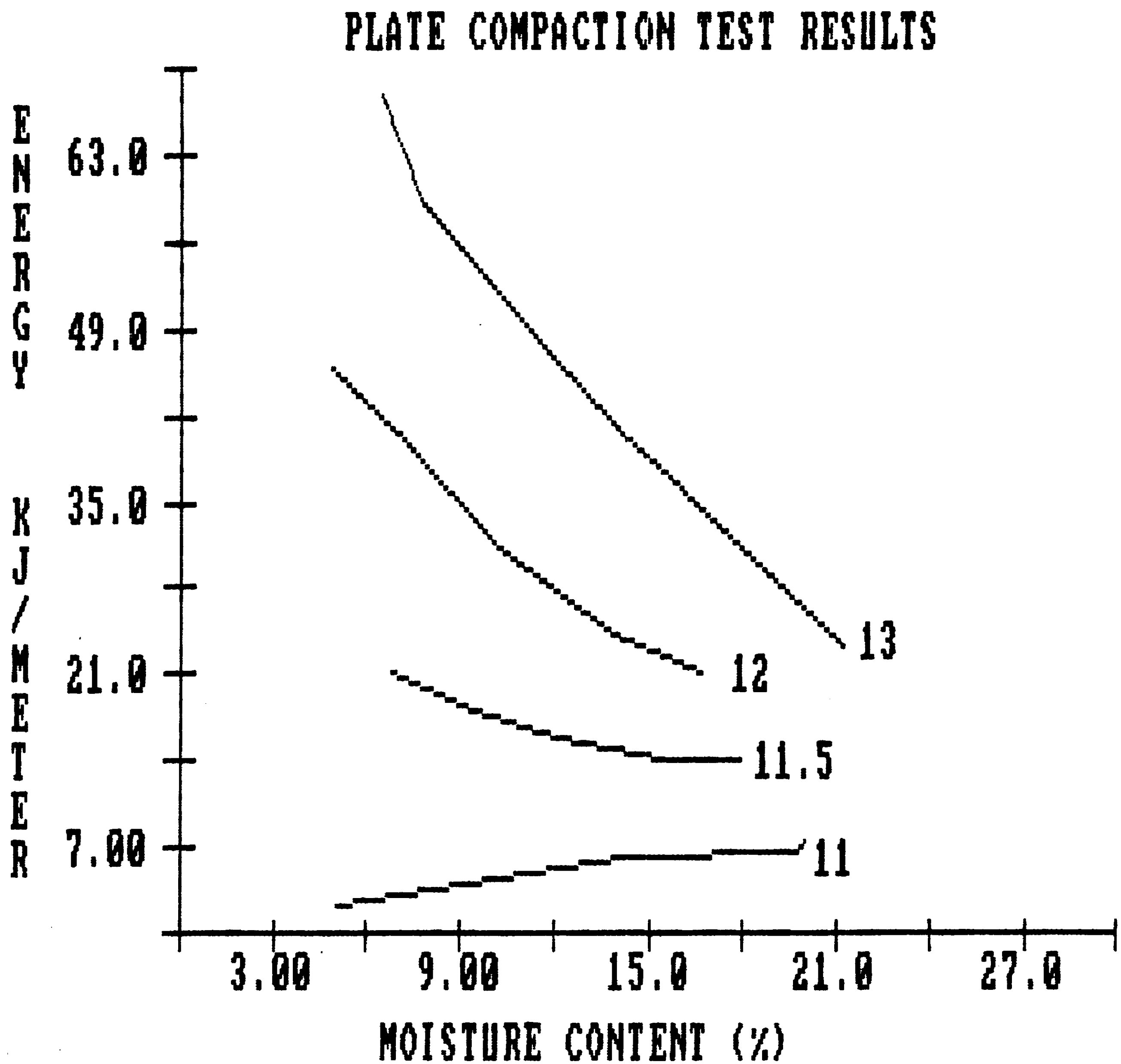


Figure 9. Compaction energy vs. moisture content for Powell soil.

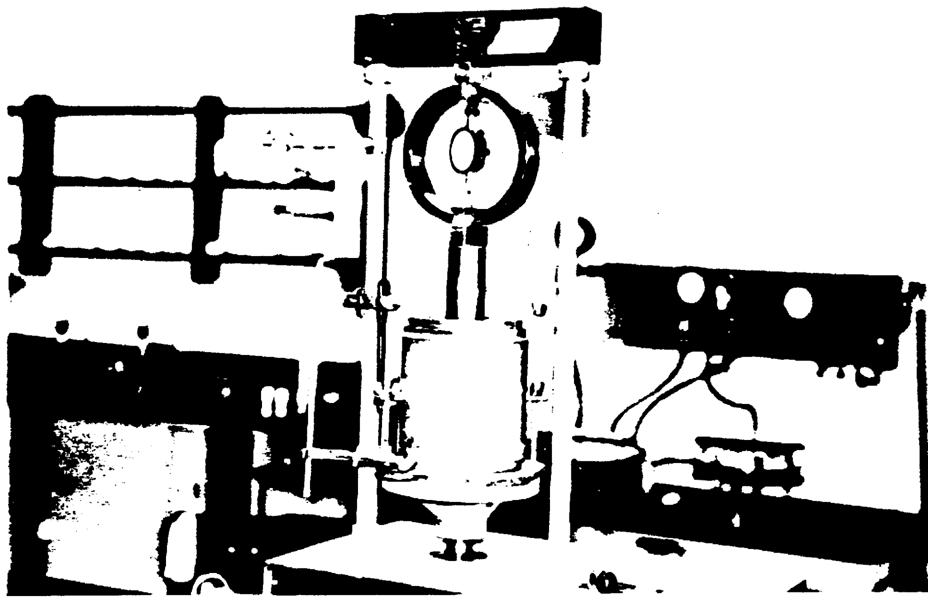


Figure 10. Compaction test equipment.

and the sample was covered immediately and set aside for 24 hours. After the sample cured, the soil was placed in the CBR compaction mold very loosely. The soil was pressed slightly into the mold until the plunger was flush with the top of the mold.

All compaction tests were run at approximately the same velocity since the velocity of compaction would affect the energy requirements (Parsons, et al. 1962). The proving ring scale was set with the compression machine on, the force readings were read at every .5 centimeters of compression until the height of the compacted sample was 11.0 centimeters giving a 2000 cubic centimeter volume compacted sample. The force versus distance was then plotted as shown in Figure 11.

The shaded area under the curve may be expressed in kilojoules per cubic meter by approximating the integral using a least squares curve fit to solve for the force versus distance function and then solving for the definite integral. The computer program, listed in the Appendix, was developed for this analysis.

Penetration resistance was then measured at the center of the molds. Resistance readings taken at the various depths were plotted as a function of the integrated dry density value and the moisture content for the sample. By using the single lift, the penetration resistance and dry density values should be representative of values obtained in the field by the single pass roller compaction machine.

After penetration resistance readings, the mold and compacted soil were weighed and two moisture content samples taken. All the values have then been obtained which will allow moisture content, compaction energy and dry density to be calculated.

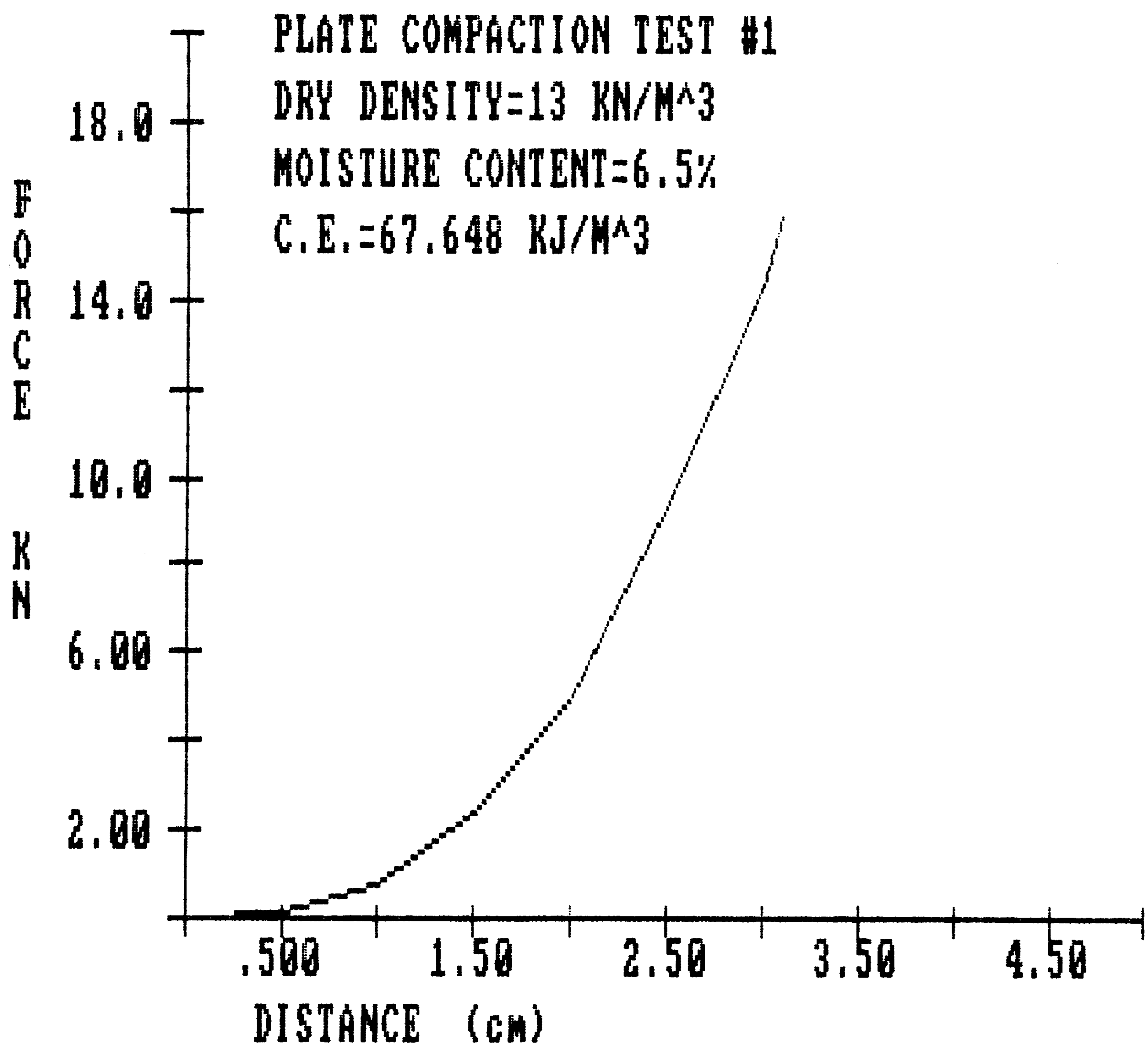


Figure 11. Force distance during compaction.

Since the soil in the field was approximately the same dry density, the furrow packer machine should apply the same energy to the soil. The iso-energy line does not imply constant dry density or moisture content (see Figure 11).

Although some of the field compaction energy is dissipated in breaking up clods at the low moisture contents, the energy curves developed will be useful in the understanding of the roller compaction system. In order to obtain field densities that will improve the irrigation characteristics, the furrows need to be approaching the sticky limit moisture content during compaction. The energy applied to the soil by the furrow compaction device more beneficial to the irrigation characteristics when applied at higher moisture contents.

Field penetration resistance values will be used to predict hydraulic and infiltration characteristics of the compacted furrows. As explained in the Results section, this analysis will require compaction of a furrow flow model before infiltration and advance characteristics of the compacted furrows can be developed. This analysis will be included in a supplemental report.

RESULTS

The data collected during the field tests included the furrow in-flows, advance and recession times, infiltration characteristics, compaction soil water content, sediment concentrations in the furrow flows and penetration resistance of the furrow bottom. Both parabolic and triangular furrows were compacted at half and full compaction weights and data were collected in wheel and non-wheel rows. Each pass through the field included one uncompacted triangular furrow.

All field data are tabulated in the Appendix. For the present, the data does demonstrate that wheel rows advanced more rapidly than non-wheel rows.

Larsen (1985) reported an opposite effect, but ran the track eliminators approximately twice as deep as the depth of operation used in these tests. Apparently, compaction caused by the tractor wheels at depths of greater than 40mm was beneficial in reducing infiltration.

The normal method of analyzing furrow flows is to assume that the water level in the furrow is at the nominal depth at a given distance along the furrow at the same time the water advancing down the furrow reaches that distance. Referring to Figure 1, the intake opportunity time at any distance is defined as the time between when the water first reaches a point and the time when water in the furrow disappears on recession. Thus, the normal definition of intake opportunity time neglects the build-up of the depth of water in the furrow and the decrease which occurs on recession. It has been demonstrated in the analysis of data from this research that these assumptions can result in over estimating the depth of water infiltrated at a given point along the furrow by a factor in excess of 100%. If one is comparing similar irrigation treatments, this error is compensating, but it becomes very significant when comparing vastly different treatments. Comparison of irrigation efficiencies and uniformities based on these assumptions would be grossly misleading.

Infiltration is significantly affected by the time rate of change of the wetted perimeter of the furrow and thus, the depth of water in the furrow. Similarly, the advance down the furrow is affected by hydraulic radius and infiltration. Therefore, when comparing the performance of differing furrow shapes, the geometry of the furrow and time rate of variation of the depth of flow must be considered. For the present research, the problem is illustrated in Figure 12. Note in the figure that water advance along the triangular furrow in a very small stream and the data indicate that the advance occurred

Figure 12a. Water advancing on triangular furrow.

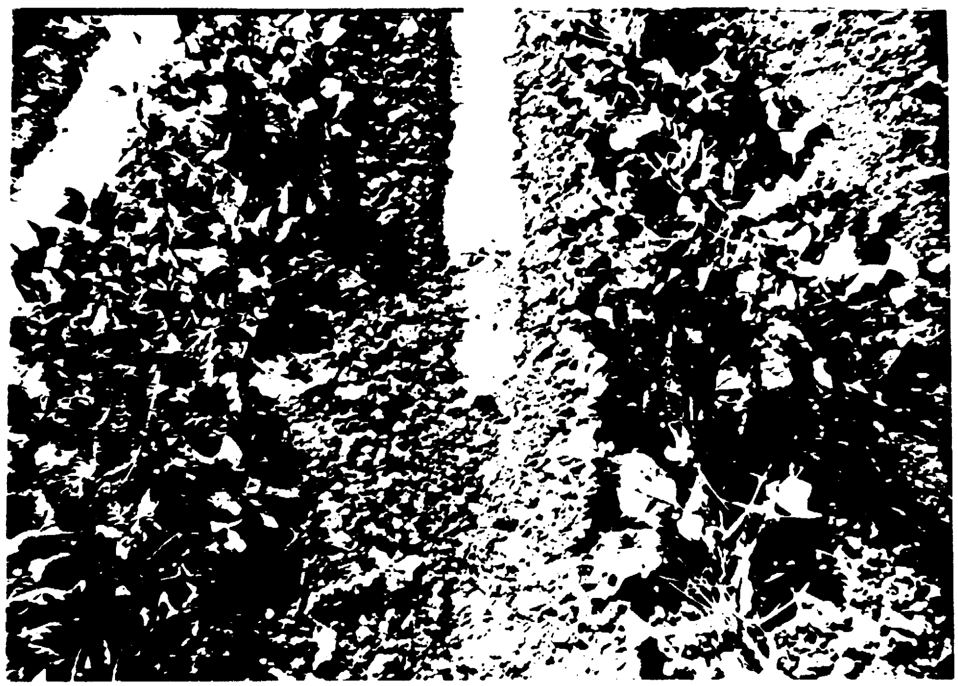


Figure 12b. Water advancing in parabolic furrow.

rapidly. However, the quantity of flow was relatively small for an extended time period, and only a small portion of the furrow was wet. The nominal depth of flow was not established down field in most triangular furrows for more than two hours after the advance front passed.

Advance and wetting occurred rather differently in the parabolic furrows. Referring to Figure 12, the advancing water front was much broader, and the quantity of wetted soil was much greater compared to the triangular furrows. Although advance was slower, the soil was wet literally from row to row within a few minutes after the advancing front passed a given point, and the nominal depth of flow was established much more rapidly than in the triangular furrows. Because of these observations, and based on preliminary analysis of the data, it was concluded that alternative procedures for data analysis were required.

The sediment data collected included steady-state samples and samples taken at time intervals for use in establishing histograms. The available data indicates the concentrations of sediment in the furrow flows at various times during the irrigation events. The difficulty with further analysis of this information is the lack of reliable furrow flow data. The quantity of sediment moving in and from the field is dependent upon the time rate of flow in the furrows and from the furrows at the end of the field. Because of the obvious difficulty with the flumes, an alternative method of evaluating furrow flows was required.

A furrow flow model is being developed which will predict the flow of water in a furrow, the depth of water in the furrow and the rate of infiltration from the furrow at any given time. The model is in the final stages of development, and is currently being calibrated against the field data. Advance data from the model compare very favorable with field data, but a minor modification must be made in the furrow water storage relationship to improve the water depth estimate. When this method of analysis is completed, the data will be evaluated and submitted in an appended report.

The authors regret that they are not able at this time to provide a detailed and satisfactory analysis of the data. However, analysis of the data by conventional methods did not provide results that were consistent with field observations. Because of time constraints, and the fact that a suitable method of evaluation was not available in the literature, it was decided that the best alternative was to proceed with the development of an improved method of analysis and provide a correct and appropriate interpretation of the data when that development is completed.

CONCLUSIONS

1. Deep compaction by the tractor tire was beneficial in reducing infiltration.

2. Furrow shape is an important consideration for improved furrow irrigation. However, when comparing different furrow shapes, it is necessary to consider the geometry of the furrow and the affect of furrow geometry on infiltration, furrow advance, and depth of water in the furrow as a function of time.

3. A model of furrow flow is being developed which will permit comparative evaluation of the triangular and parabolic furrows considered in this research. It will also provide the necessary flow data required to evaluate sediment transport from the furrows.

4. Using a plate compaction test, field furrow soil penetration resistance and the results of furrow hydraulic and infiltration tests, a procedure can be developed to predict the level of compaction required to produce desired furrow irrigation results.

5. An appended report will be submitted when the analysis of data is satisfactorily completed.

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APPENDIX

PLATE COMPACTION TEST RESULTS

DRY DENSITY (KN/CUBIC M.)	MOISTURE CONTENT (%)	VOLUMETRIC COMPACTION ENERGY (KJ/CUBIC M.)
11	5.0	2.261
11	9.1	4.065
11	14.3	6.217
11	19.8	6.759
11	20.0	7.656
11.5	6.8	21.057
11.5	9.4	18.040
11.5	12.1	15.777
11.5	15.4	14.308
11.5	17.9	14.181
12	4.9	45.871
12	7.0	40.457
12	10.2	31.286
12	13.9	24.070
12	16.7	20.970
13	6.5	67.648
13	7.8	58.971
13	12.4	45.503
13	14.3	40.246
13	21.2	23.225

PLATE COMPACTION TEST # 1

DATE OF TESTING : 8-2-85

DRY DENSITY : 13 KN/m^3

MOISTURE CONTENT : 6.5%

FINAL COMPACTION VOLUME : 2000 cm^3

FINAL COMPACTION DEPTH : 11 cm

Di(cm)	Fi(KN)
0.5	0.148
1.0	0.812
1.5	2.370
2.0	4.940
2.5	9.300
3.0	14.300
3.1	15.800

$F(x) = 0.849\ X^{2.572}$ KN

r=1.000

COMPACTION ENERGY= 0.135 KJ
VOLUMETRIC COMPACTION ENERGY= 67.648 KJ/m^3

PLATE COMPACTION TEST # 3

DATE OF TESTING : 8-8-85

DRY DENSITY : 12 KN/m^3

MOISTURE CONTENT : 10.2%

FINAL COMPACTION VOLUME : 2000 cm^3

FINAL COMPACTION DEPTH : 11 cm

Di(cm)	Fi(KN)
0.5	0.131
1.0	0.370
1.5	0.871
2.0	1.870
2.5	3.500
3.0	5.470
3.3	6.670

F(x)= 0.458 X^ 2.151KN

r=0.992

COMPACTION ENERGY= 0.063 KJ
VOLUMETRIC COMPACTION ENERGY= 31.286 KJ/m^3

```
60 REM  THIS PROGRAM GIVES A CURVE FIT SOLUTION
100 CLS
110 CLEAR
120 INPUT " PLATE COMPACTION TEST #";PLATENUM
130 CLS
140 LINE INPUT "DATE OF TESTING ? ";DATES$
150 CLS
160 INPUT "DRY DENSITY (KN/m^3)";DRYDENS
170 CLS
180 INPUT "MOISTURE CONTENT (%)";MOISTCONT
190 CLS
200 INPUT "FINAL COMPACTION VOLUME (cm^3)";COMPVOL
210 CLS
220 INPUT "FINAL COMPACTION DEPTH (cm)";FCDEPTH
230 CLS
240 INPUT "HOW MANY SETS OF DATA POINTS WILL YOU BE ENTERING";X
250 DIM D(X):DIM F(X)
260 CLS
270 FOR L=1 TO X
280 PRINT "DISTANCE # "L" (cm)?":INPUT DIST
290 D(L)=DIST
300 PRINT
310 PRINT "FORCE # "L" (KN)?":INPUT FORCE
320 F(L)=FORCE
330 CLS
340 NEXT L
350 INPUT "WOULD YOU LIKE A PRINT OUT (Y OR N) ";PRNT$
360 REM
370 REM CALCULATE D AND F AVERAGES
380 REM
390 DY=0:FY=0
400 FOR L=1 TO X
410 DY=DY+LOG(D(L))
420 FY=FY+LOG(F(L))
430 NEXT L
440 DAV=DY/X
450 FAV=FY/X
460 REM
470 REM CALCULATE SSX,SSY,SSXY
480 REM
490 FOR L=1 TO X
500 A=((LOG(D(L)))-(DAV))^2
510 SSX=SSX+A
520 B=((LOG(F(L)))-(FAV))^2
530 SSY=SSY+B
540 F=((LOG(D(L)))-(DAV))*((LOG(F(L)))-(FAV))
550 SSXY=SSXY+F
560 NEXT L
570 REM
580 REM CALCULATE A,B,R
590 REM
```

```
600 B=SSXY/SSX
610 R=SSXY/((SSX*SSY)^.5)
620 A=EXP(FAV-(B*DAV))
630 REM CALCULATE WORK BY INTEGRATING FORCE EQUATION
640 REM CALCULATE VOLUMETRIC COMPACTION ENERGY USING WORK
670 WORK=((A/(B+1))/100)*(D(X)^(B+1))
680 CE=WORK/2*1000
690 REM
700 REM        ********** PRINT OUT **********
710 REM
720 CLS
730 PRINT "    PLATE COMPACTION TEST #"PLATENUM
740 PRINT "    DATE OF TESTING : "DATES$
750 PRINT "    DRY DENSITY : "DRYDENS"KN/m^3"
760 PRINT "    MOISTURE CONTENT : "MOISTCONT"%"
770 PRINT "    FINAL COMPACTION VOLUME : "COMPVOL"cm^3"
780 PRINT "    FINAL COMPACTION DEPTH : "FCDEPTH"cm"
790 PRINT
800 PRINT"              -------------------------"
810 PRINT"                 Di(cm)        Fi(KN)"
820 PRINT"                 ------        ------"
830 FOR L=1 TO X
840 PRINT USING "                 ###.#";D(L);
850 PRINT USING "       ###.###";F(L)
860 NEXT L
870 PRINT"              -------------------------"
880 PRINT
890 PRINT "  F(x)=";:PRINT USING "###.###";A;:PRINT" X^ ";
900 PRINT USING "#.###";B;:PRINT"KN"
920 PRINT "      r=";:PRINT USING "###.###";R
930 PRINT "   COMPACTION ENERGY=";:PRINT USING "###.###";WORK;:PRINT "KJ"
940 PRINT "   VOLUMETRIC COMPACTION ENERGY= ";:PRINT USING "###.###";CE;
950 PRINT "KJ/m^3"
960 REM     ********** PRINTER PRINT OUT ***********
970 IF PRNT$="N" THEN END
980 FOR L=1 TO 10:LPRINT:NEXT L
990 LPRINT "                        PLATE COMPACTION TEST #"PLATENUM
1000 LPRINT
1010 LPRINT "            DATE OF TESTING : "DATES$
1020 LPRINT
1030 LPRINT "            DRY DENSITY : "DRYDENS"KN/m^3"
1040 LPRINT
1050 LPRINT "            MOISTURE CONTENT : ";:LPRINT USING "##.#";MOISTCONT;
1060 LPRINT "%":LPRINT
1070 LPRINT "            FINAL COMPACTION VOLUME : "COMPVOL"cm^3"
1080 LPRINT
1090 LPRINT "            FINAL COMPACTION DEPTH : "FCDEPTH"cm"
1100 LPRINT:LPRINT
1110 LPRINT"                      -------------------------"
1120 LPRINT"                         Di(cm)        Fi(KN)"
1130 LPRINT"                         ------        ------"
1140 FOR L=1 TO X
```

```
1150 LPRINT USING "                          ###.#";D(L);
1160 LPRINT USING "       ###.###";F(L)
1170 NEXT L
1180 LPRINT"                            -------------------------"
1190 LPRINT:LPRINT
1200 LPRINT "             F(x)=";:LPRINT USING "###.###";A;:LPRINT" X^ ";
1210 LPRINT USING "#.###";B;: LPRINT"KN":LPRINT
1220 LPRINT "                   r=";:LPRINT USING "#.###";R:LPRINT
1230 LPRINT "             COMPACTION ENERGY=";:LPRINT USING "##.###";WORK;
1240 LPRINT " KJ"
1250 LPRINT "             VOLUMETRIC COMPACTION ENERGY= ";
1260 LPRINT USING "##.###";CE;
1270 LPRINT " KJ/m^3"
1275 P=66-(35+X):FOR L=1 TO P:LPRINT:NEXT L
1280 END
```

IRRIGATION #1

LOCATION: UNIVERSITY OF WYOMING EXPERIMENTAL STATION,
POWELL, WYOMING.

DATES: JUNE 11-13, 1985

SOIL TYPE: CLAY LOAM

TRACTOR: JOHN DEERE 630

TRACTOR SPEED DURING COMPACTION: 2.4 KILOMETERS/HOUR

SOIL MOISTURE CONTENT DURING COMPACTION: 4.0 %

FURROW INFLOW: VARIED FROM ABOUT 80-120 LITERS/MINUTE.

FIELD SLOPE: .004

BEANS -@ POWELL   IRRIGATED 6/12/85

ROW # 27   TRIANGULAR / HALF WEIGHT

WHEEL ROW   ROW WIDHT.762m

CULTIVATED   WATER DEPTH 7.8 cm

Ti	Di
2	0.197
5	1.713
10	2.471
20	3.562
50	5.442
110	9.170

r=0.925

d= 0.239T^0.838CM

I= 12.012T^-.162cm/hr

BEANS -@ POWELL IRRIGATED 6/12/85

ROW # 30 TRIANGULAR / HALF WEIGHT

SOFT ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 7.8 cm

Ti	Di
1	0.167
2	0.318
5	0.637
10	0.985
15	1.243
30	1.955
60	3.168
120	5.639

r=0.998

d= 0.185T`0.708CM

I= 7.857T`-.292cm/hr

BEANS -@ POWELL IRRIGATED 6/12/85

ROW # 6 PARABOLIC / FULL WEIGHT

SOFT ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 6 cm

Ti	Di
1	0.288
2	0.576
5	1.243
10	2.001
15	2.607
30	4.032
60	6.320
120	10.929

r=0.997

d= 0.337T^0.735CM

I= 14.864T^-.265cm/hr

BEANS -@ POWELL   IRRIGATED 6/12/85

ROW # 10   TRIANGULAR / FULL WEIGHT

SOFT ROW   ROW WIDHT.762m

CULTIVATED   WATER DEPTH 7.8 cm

Ti	Di
--	--
1	0.091
2	0.212
5	0.455
10	0.925
15	1.349
30	2.486
60	5.775
120	9.216

r=0.999

$d= 0.099T^{0.965}$ CM

$I= 5.706T^{-.035}$ cm/hr

BEANS -@ POWELL IRRIGATED 6/12/85

ROW # 7 TRIANGULAR / FULL WEIGHT

WHEEL ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 7.8 cm

Ti	Di
1	0.333
2	0.606
5	1.258
10	2.077
15	2.774
30	4.456
60	7.018
120	11.550

r=0.999

d= 0.364T^0.732CM

I= 16.000T^-.268cm/hr

BEANS -@ POWELL IRRIGATED 6/12/85

ROW # 26 PARABOLIC / HALF WEIGHT

SOFT ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 6 cm

Ti	Di
--	--
1	0.030
2	0.030
7	0.637
12	1.364
27	2.804
57	5.563
117	10.216

r=0.976

d= 0.028T^1.337CM

I= 2.219T^0.337cm/hr

BEANS -@ POWELL   IRRIGATED 6/12/85

ROW # 9   PARABOLIC / FULL WEIGHT

WHEEL ROW   ROW WIDHT.762m

CULTIVATED   WATER DEPTH 6 cm

Ti	Di
--	--
1	0.152
2	0.318
5	0.819
10	1.455
15	1.955
30	3.259
60	5.442
120	9.261

r=0.996

d= 0.182T¨0.845CM

I= 9.209T^-.155cm/hr

BEANS -@ POWELL IRRIGATED 6/12/85

ROW # 29 PARABOLIC / HALF WEIGHT

WHEEL ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 6 cm

Ti	Di
1	0.076
2	0.182
5	0.470
10	0.834
15	1.076
30	1.667
60	2.683
120	4.500

r=0.992

d= 0.102T^0.824CM

I= 5.029T^-.176cm/hr

BEANS -@ POWELL IRRIGATED 6/12/85

ROW # 28 CHECK

SOFT ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 7.8 cm

Ti	Di
--	--
1	0.227
2	0.394
5	0.803
10	1.182
15	2.016
30	3.062
60	5.154
120	7.685

r=0.998

d= 0.235T`0.746CM

I= 10.519T`-.254cm/hr

BEANS -@ POWELL IRRIGATED 6/12/85

ROW # 8 CHECK

SOFT ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 7.8 cm

Ti	Di
1	0.197
2	0.364
5	0.728
10	1.197
15	1.531
30	2.425
60	4.002
120	8.579

r=0.998

d= 0.205T 0.752CM

I= 9.270T^-.248cm/hr

IRRIGATION #1

ADVANCE DATA 6/13/85

ROW #	ROW TYPE	ADVANCE TIMES AT DISTANCE 160 M	320 M
1	TNFW	38	156
2	PWFW	82	488
3	C	33	276
4	TWFW	30	402
5	PNFW	43	411
6	PNFW	219	549
7	TWFW	30	185
8	C	85	483
9	PWFW	53	418
10	TNFW	66	538
11	TNFW	40	262
12	PWFW	88	479
13	C	51	207
14	TWFW	65	450
15	PNFW	41	403
16	PNFW	186	533
17	TWFW	74	157
18	C	46	249
19	PWFW	36	138
20	TNFW	68	517
21	TNHW	43	135
22	PWHW	115	430
23	C	110	423
24	TWHW	219	530
25	PNHW	122	507
26	PNHW	269	570
27	TWHW	101	380
28	C	78	332
29	PWHW	70	371
30	TNHW	70	439
31	TNHW	58	321
32	PWHW	55	183
33	C	52	229
34	TWHW	151	553
35	PNHW	191	476
36	PNHW	218	596
37	TWHW	115	476
38	C	101	546
39	PWHW	77	462
40	TNHW	68	220

IRRIGATION #2

LOCATION: UNIVERSITY OF WYOMING EXPERIMENTAL STATION,
POWELL, WYOMING.

DATES: JULY 6-8, 1985

SOIL TYPE: CLAY LOAM

TRACTOR: JOHN DEERE 630

TRACTOR SPEED DURING COMPACTION: 2.4 KILOMETERS/HOUR

SOIL MOISTURE CONTENT DURING COMPACTION: 9.0 %

FURROW INFLOW: 61 LITERS/MINUTE.

FIELD SLOPE: .004

BEANS -@ POWELL IRRIGATED 7/7/85

ROW # 35 TRIANGULAR / HALF WEIGHT

SOFT ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 7.8 cm

Ti	Di
--	--
1	0.136
2	0.303
5	0.652
10	0.985
15	1.228
30	1.910
60	3.016
120	5.002

r=0.994

d= 0.171T^0.717CM

I= 7.367T^-.283cm/hr

BEANS -@ POWELL IRRIGATED 7/7/85

ROW # 17 TRIANGULAR / FULL WEIGHT

WHEEL ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 7.8 cm

Ti	Di
--	--
1	0.273
2	0.500
5	0.985
10	1.576
15	2.001
30	2.850
60	4.350
120	7.367

r=0.997

d= 0.310T`0.665CM

I= 12.360T -.335cm/hr

BEANS -@ POWELL IRRIGATED 7/7/85

ROW # 37 TRIANGULAR / HALF WEIGHT

WHEEL ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 7.8 cm

Ti	Di
1	0.258
2	0.515
5	1.152
10	1.773
15	2.243
30	3.350
60	4.805
120	7.700

r=0.993

d= 0.320T^0.685CM

I= 13.171T^-.315cm/hr

BEANS -@ POWELL   IRRIGATED 7/7/85

ROW # 16   PARABOLIC / FULL WEIGHT

SOFT ROW   ROW WIDHT.762m

CULTIVATED   WATER DEPTH 6 cm

Ti	Di
--	--
1	0.394
2	0.773
5	1.682
10	3.016
15	3.698
30	5.866
60	8.822
120	13.778

r=0.995

d= 0.471T^0.732CM

I= 20.670T^-.268cm/hr

BEANS -@ POWELL IRRIGATED 7/7/85

ROW # 20 TRIANGULAR / FULL WEIGHT

SOFT ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 7.8 cm

Ti	Di
--	--
1	0.288
2	0.621
5	1.288
10	2.228
15	2.986
30	4.896
60	8.306
120	14.339

r=0.998

d= 0.334T`0.794CM

I= 15.923T^-.206cm/hr

BEANS -@ POWELL   IRRIGATED 7/7/85

ROW # 19   PARABOLIC / FULL WEIGHT

WHEEL ROW   ROW WIDHT.762m

CULTIVATED   WATER DEPTH 6 cm

Ti	Di
1	0.121
2	0.303
5	0.728
10	1.182
15	1.637
30	2.501
60	4.426
120	6.988

r=0.993

d= 0.160T^0.818CM

I= 7.869T^-.182cm/hr

BEANS -@ POWELL IRRIGATED 7/7/85

ROW # 36 PARABOLIC / HALF WEIGHT

SOFT ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 6 cm

Ti	Di
1	0.485
2	0.712
5	1.425
10	2.334
15	2.986
30	4.956
60	7.897
120	12.944

r=1.000

d= 0.465T^0.693CM

I= 19.346T^-.307cm/hr

BEANS -@ POWELL IRRIGATED 7/7/85

ROW # 34 PARABOLIC / HALF WEIGHT

WHEEL ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 6 cm

Ti	Di
1	0.349
2	0.515
5	0.925
10	1.334
15	1.470
30	2.228
60	3.698
120	6.351

r=0.996

d= 0.340T^0.586CM

I= 11.933T^-.414cm/hr

BEANS -@ POWELL IRRIGATED 7/7/85

ROW # 33 CHECK

SOFT ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 7.8 cm

Ti	Di
1	0.637
2	0.955
5	1.803
10	2.789
15	3.546
30	5.153
60	7.412
120	10.837

r=0.999

d= 0.665T^0.596CM

I= 23.767T^-.404cm/hr

BEANS -@ POWELL IRRIGATED 7/7/85

ROW # 18 CHECK

SOFT ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 7.8 cm

Ti	Di
1	0.167
2	0.424
5	1.016
10	1.849
15	2.531
30	4.517
60	6.881
120	10.459

r=0.992

d= 0.224T`0.851CM

I= 11.427T`-.149cm/hr

IRRIGATION #2

ADVANCE DATA 7/8/85

ROW #	ROW TYPE	ADVANCE TIMES AT DISTANCE 160 M	320 M
1	TNFW	**	**
2	PWFW	69	327
3	C	65	344
4	TWFW	65	240
5	PNFW	63	224
6	TNHW	120	596
7	PWHW	49	122
8	C	271	593
9	TWHW	49	105
10	PNHW	85	488
11	TNHW	76	475
12	PWHW	57	161
13	C	50	108
14	TWHW	52	128
15	PNHW	51	260
16	TNFW	209	534
17	PWFW	65	185
18	C	101	538
19	TWFW	48	105
20	PNFW	78	479
21	TNFW	96	517
22	PWFW	45	82
23	C	73	382
24	TWFW	53	163
25	PNFW	57	253
26	TNFW	385	736
27	PWFW	64	155
28	C	78	519
29	TWFW	67	133
30	PNFW	143	666
31	TNHW	171	682
32	PWHW	66	266
33	C	89	509
34	TWHW	70	245
35	PNHW	54	142
36	TNHW	257	**
37	PWHW	52	141
38	C	361	**
39	TWHW	48	121
40	PNHW	323	**

** NO DATA

IRRIGATION #3

LOCATION: UNIVERSITY OF WYOMING EXPERIMENTAL STATION,
POWELL, WYOMING.

DATES: JULY 21-23, 1985

SOIL TYPE: CLAY LOAM

TRACTOR: JOHN DEERE 630

TRACTOR SPEED DURING COMPACTION: 2.4 KILOMETERS/HOUR

SOIL MOISTURE CONTENT DURING COMPACTION: 18.9 %

FURROW INFLOW: 77.4 LITERS/MINUTE.

FIELD SLOPE: .004

BEANS -@ POWELL IRRIGATED 7/22/85

ROW # 29 TRIANGULAR / FULL WEIGHT

WHEEL ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 7.8 cm

Ti	Di
--	--
1	0.409
2	0.424
5	0.712
10	0.925
15	1.016
30	1.334
60	1.940
120	3.001

r=0.990

d= 0.354T¨0.418CM

I= 8.892Tˆ-.582cm/hr

BEANS -@ POWELL   IRRIGATED 7/22/85

ROW # 12   TRIANGULAR / HALF WEIGHT

WHEEL ROW   ROW WIDHT.762m

CULTIVATED   WATER DEPTH 7.8 cm

Ti	Di
--	--
1	0.212
2	0.409
5	0.773
10	1.152
15	1.304
30	1.834
60	2.592
120	3.683

r=0.991

d= 0.265T^0.571CM

I= 9.080T^-.429cm/hr

BEANS -@ POWELL IRRIGATED 7/22/85

ROW # 26 TRIANGULAR / FULL WEIGHT

SOFT ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 7.8 cm

Ti	Di
1	0.379
2	0.682
5	1.349
10	2.183
15	2.819
30	4.335
60	6.684
120	10.686

r=0.999

d= 0.419T^0.686CM

I= 17.273T^-.314cm/hr

BEANS -@ POWELL IRRIGATED 7/22/85

ROW # 15 TRIANGULAR / HALF WEIGHT

SOFT ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 7.8 cm

Ti	Di
--	--
1	0.152
2	0.318
5	0.743
10	1.182
15	1.501
30	2.319
60	3.805
120	6.230

r=0.995

d= 0.186T`0.751CM

I= 8.376T`-.249cm/hr

BEANS -@ POWELL IRRIGATED 7/22/85

ROW # 28 CHECK

SOFT ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 7.8 cm

Ti	Di
1	0.333
2	0.576
5	0.758
10	0.985
15	1.182
30	1.667
60	2.577
120	4.244

r=0.991

d= $0.343T^{0.494}$CM

I= $10.175T^{-.506}$cm/hr

BEANS -@ POWELL IRRIGATED 7/22/85

ROW # 27 PARABOLIC / FULL WEIGHT

WHEEL ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 6 cm

Ti	Di
--	--
1	0.288
2	0.515
5	1.016
10	1.394
30	2.107
60	2.895
120	4.502

r=0.990

d= 0.349T`0.540CM

I= 11.311T^-.460cm/hr

BEANS -@ POWELL   IRRIGATED 7/22/85

ROW # 14   PARABOLIC / HALF WEIGHT

WHEEL ROW   ROW WIDHT.762m

CULTIVATED   WATER DEPTH 6 cm

Ti	Di
--	--
1	0.121
2	0.243
5	0.424
10	0.561
15	0.667
30	0.940
60	1.425
120	2.425

r=0.993

d= 0.144T'0.578CM

I= 4.987T^-.422cm/hr

BEANS -@ POWELL IRRIGATED 7/22/85

ROW # 30 PARABOLIC / FULL WEIGHT

SOFT ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 6 cm

Ti	Di
1	0.819
2	1.091
5	1.637
10	2.289
15	2.850
30	4.229
60	6.154
120	9.640

r=0.997

d= 0.752T^0.513CM

I= 23.166T^-.487cm/hr

BEANS -@ POWELL IRRIGATED 7/22/85

ROW # 11 PARABOLIC / HALF WEIGHT

WHEEL ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 6 cm

Ti	Di
1	0.212
2	0.500
5	0.985
10	1.546
15	2.061
30	3.319
60	5.578
120	9.534

r=0.997

d= 0.259T^0.759CM

I= 11.801T^-.241cm/hr

IRRIGATION #3

ADVANCE DATA 7/23/85

ROW #	ROW TYPE	ADVANCE TIMES AT DISTANCE 160 M	320 M
1	TNFW	70	309
2	PWFW	36	80
3	C	49	177
4	TWFW	33	101
5	PNFW	69	252
6	TNHW	53	311
7	PWHW	34	85
8	C	114	604
9	TWHW	34	97
10	PNHW	242	665
11	PNHW	59	386
12	TWHW	25	64
13	C	49	126
14	PWHW	28	71
15	TNHW	37	195
16	TNHW	51	148
17	PWHW	29	71
18	C	76	489
19	TWHW	24	73
20	PNHW	232	639
21	PNFW	57	269
22	TWFW	23	59
23	C	72	309
24	PWFW	25	63
25	TNFW	56	505
26	TNFW	67	410
27	PWFW	29	69
28	C	53	285
29	TWFW	26	71
30	PNFW	62	270
31	PNHW	110	599
32	TWHW	23	74
33	C	14	341
34	PWHW	28	158
35	TNHW	39	158
36	PNFW	245	647
37	TWFW	25	99
38	C	50	785
39	PWFW	23	71
40	TNFW	125	931

IRRIGATION #4

LOCATION: UNIVERSITY OF WYOMING EXPERIMENTAL STATION,
POWELL, WYOMING.

DATES: AUGUST 11-13, 1985

SOIL TYPE: CLAY LOAM

TRACTOR: JOHN DEERE 630

TRACTOR SPEED DURING COMPACTION: 2.4 KILOMETERS/HOUR

SOIL MOISTURE CONTENT DURING COMPACTION: 5.5 %

FURROW INFLOW: 81.4 LITERS/MINUTE.

FIELD SLOPE: .004

BEANS -@ POWELL   IRRIGATED 8/12/85

ROW # 8   CHECK

SOFT ROW   ROW WIDHT.762m

CULTIVATED   WATER DEPTH 7.8 cm

Ti	Di
--	--
1	0.379
2	0.758
5	1.425
10	2.349
15	3.107
30	4.608
60	7.988
120	12.687

r=0.998

d= 0.429T^0.715CM

I= 18.413T^-.285cm/hr

BEANS -@ POWELL IRRIGATED 8/12/85

ROW # 7 PARABOLIC / HALF WEIGHT

WHEEL ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 6 cm

Ti	Di
1	0.515
2	0.697
5	1.106
10	1.485
15	1.758
30	2.440
60	3.138
120	4.381

r=0.999

d= 0.523T^0.446CM

I= 13.986T`-.554cm/hr

BEANS -@ POWELL IRRIGATED 8/12/85

ROW # 10 PARABOLIC / HALF WEIGHT

SOFT ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 6 cm

Ti	Di
--	--
1	0.227
2	0.546
5	1.304
10	1.728
15	2.395
30	3.592
60	6.700
120	11.156

r=0.993

d= 0.290T^0.770CM

I= 13.401T^-.230cm/hr

BEANS -@ POWELL IRRIGATED 8/12/85

ROW # 24 PARABOLIC / FULL WEIGHT

WHEEL ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 6 cm

Ti	Di
1	0.152
2	0.349
5	0.834
10	1.182
15	1.470
30	2.107
60	3.213
120	4.926

r=0.987

d= 0.208T^0.688CM

I= 8.606T^-.312cm/hr

BEANS -@ POWELL IRRIGATED 8/12/85

ROW # 21 PARABOLIC / FULL WEIGHT

SOFT ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 6 cm

Ti	Di
1	0.273
2	0.515
5	1.061
10	1.652
15	2.092
30	3.153
60	4.911
120	8.018

r=0.997

d= $0.314T^{0.685}$CM

I= $12.906T^{-.315}$cm/hr

BEANS -@ POWELL IRRIGATED 8/12/85

ROW # 9 TRIANGULAR / HALF WEIGHT

WHEEL ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 7.8 cm

Ti	Di
1	0.197
2	0.318
5	0.576
10	0.894
15	1.228
30	2.168
60	3.971
124	6.957

r=0.998

d= 0.182T^0.739CM

I= 8.057T^-.261cm/hr

BEANS -@ POWELL   IRRIGATED 8/12/85

ROW # 6   TRIANGULAR / HALF WEIGHT

SOFT ROW   ROW WIDHT.762m

CULTIVATED   WATER DEPTH 7.8 cm

Ti	Di
--	--
1	0.227
2	0.500
5	1.076
10	1.773
15	2.365
30	3.244
60	4.714
120	7.331

r=0.990

d= 0.299T¨0.699CM

I= 12.555T^-.301cm/hr

BEANS -@ POWELL IRRIGATED 8/12/85

ROW # 22 TRIANGULAR / FULL WEIGHT

WHEEL ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 7.8 cm

Ti	Di
1	0.167
2	0.349
5	0.743
10	1.197
15	1.501
30	2.152
60	3.138
120	4.471

r=0.990

d= 0.216T¨0.669CM

I= 8.678T¨-.331cm/hr

BEANS -@ POWELL IRRIGATED 8/12/85

ROW # 25 TRIANGULAR / FULL WEIGHT

SOFT ROW ROW WIDHT.762m

CULTIVATED WATER DEPTH 7.8 cm

Ti	Di
--	--
1	0.318
2	0.682
5	1.258
10	1.925
15	2.471
30	3.911
60	6.108
120	9.928

r=0.997

d= 0.378T^0.689CM

I= 15.644T`-.311cm/hr

IRRIGATION #4

ADVANCE DATA 8/13/85

ROW #	ROW TYPE	ADVANCE TIMES AT DISTANCE 160 M	320 M
1	PNFW	141	612
2	TWFW	93	359
3	C	105	613
4	PWFW	78	267
5	TNFW	137	454
6	TNHW	160	476
7	PWHW	56	150
8	C	258	514
9	TWHW	49	160
10	PNHW	313	559
11	PNHW	159	470
12	TWHW	44	134
13	C	103	356
14	PWHW	38	134
15	TNHW	117	445
16	TNFW	192	460
17	PWFW	74	155
18	C	176	480
19	TWFW	61	146
20	PNFW	256	500
21	PNFW	170	455
22	TWFW	65	162
23	C	144	434
24	PWFW	52	160
25	TNFW	190	478
26	TNHW	268	507
27	PWHW	55	140
28	C	165	455
29	TWHW	36	106
30	PNHW	231	507
31	TNFW	184	468
32	PWFW	61	160
33	C	234	519
34	TWFW	96	255
35	PNFW	195	457
36	PNHW	244	471
37	TWHW	143	357
38	C	235	492
39	PWHW	104	356
40	TNHW	253	603