3-1974

Furrow irrigation of corn with water and dairy manure slurry

James Baxter Wills

To the Graduate Council:

I am submitting herewith a thesis written by James Baxter Wills entitled "Furrow irrigation of corn with water and dairy manure slurry." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering.

John I. Sewell, Major Professor

We have read this thesis and recommend its acceptance:

John J. McDow, Curtis H. Shelton, Horace Smith

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

December 3, 1973

To the Graduate Council:

I am submitting herewith a thesis written by James Baxter Wills entitled "Furrow Irrigation of Corn with Water and Dairy Manure Slurry." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Mechanization.

John I. Sewell
Major Professor

We have read this thesis
and recommend its acceptance:

Curtis H. Shelton

Horace C. Smith

Accepted for the Council:

Hilton A. Smith
Vice Chancellor for
Graduate Studies and Research

FURROW IRRIGATION OF CORN WITH WATER
AND DAIRY MANURE SLURRY

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

---

by

James Baxter Wills

March 1974

ACKNOWLEDGEMENTS

The author wishes to sincerely express his appreciation to Dr. John I. Sewell, Professor and Associate Head, Agricultural Engineering, for his guidance and patience while serving as major professor.

The author thanks Dr. John J. McDow, Former Head of the Agricultural Engineering Department and now Dean of Admissions and Records, Mr. Curtis H. Shelton, Associate Professor, Agricultural Engineering, and Mr. Horace Smith, Associate Professor, Plant and Soil Science Department, for serving as committee members.

Appreciation is also extended to Dr. James A. Mullins and Mr. Haywood Luck of the West Tennessee Experiment Station for their excellent cooperation and assistance in carrying out this research.

The author wishes to thank his wife for her patience and assistance in typing the manuscript.

ABSTRACT

The purpose of this research was to determine the benefits and feasibility of irrigation using both water and a dairy manure slurry on corn silage yields. The influence of soil types and soil properties on corn silage yields were also studied.

Corn silage at the West Tennessee Experiment Station, Jackson, Tennessee was irrigated for three growing seasons with water only. Gated aluminum pipe delivered irrigation water to the furrows between corn rows. The corn silage was harvested using a silage chopper, and plot yields were obtained.

Corn silage at the Cherokee Dairy Farm, Knoxville, Tennessee was irrigated for three growing seasons using a dairy manure slurry. The manure slurry was delivered to the furrows by gated aluminum pipe. Corn silage was harvested by hand cutting to determine plot yields. In both locations, the value of irrigation was determined by measuring the increase in the corn silage yields compared to non-irrigated plots at each location.

Irrigation can increase corn silage yields even in years of near normal rainfall. Irrigation with both water and dairy manure slurry resulted in increased yields. Soil types also influenced corn silage yields on irrigated areas but only to a slight extent when the soil types were similar.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

I. PURPOSE OF IRRIGATION

The purpose of irrigation is to artificially supply water to crop soil to obtain optimum plant growth during growing seasons having insufficient natural rainfall. Experimental data have proved that supplemental irrigation generally results in increased crop yields. The means by which the water is supplied and the number of applications necessary in a growing season can be used to assist in determining the feasibility of irrigation.

Irrigation has several advantages such as controls soil moisture to overcome drought, increases efficiency of soil moisture during the growing season, aids control of crop pests and diseases, softens clods and dissolves plant foods, aids beneficial bacteria and chemical activities in the soil, and in dry years often results in increased yields and net profit, especially in high-value crops, if properly planned and managed.

II. OBJECTIVES

The objectives of this experimental study were (1) to determine the feasibility and benefits of furrow irrigation of corn on a graded West Tennessee Bottomland, (2) to determine the feasibility and benefits of furrow irrigation of corn on an East Tennessee stream terrace using manure slurry from a nearby dairy barn, and (3) to determine to some degree the influence of soil types and properties upon corn yield as related to furrow irrigation applications.

A secondary objective, although not intended to be a thorough economic evaluation, was to determine an approximate cost per acre for furrow irrigation of corn on the experimental plots and to attempt an extrapolation of this data to other areas with similar conditions.

III. LAND PREPARATION FOR FURROW IRRIGATION

The graded furrow method of irrigation is adaptable to most areas where the depth of productive soil and the topography of the surface will permit land grading at a reasonable cost and without permanent reduction in soil productivity. This method is best adaptable to medium-to-moderately-fine textured loams, silt loams, and clay loams because of their relatively high available water holding capacity and intake rates that will permit irrigation with a minimum of water loss to deep percolation or tail water at the ends of the furrows (27).

The first step in land preparation is to make a topographical map of the areas to be irrigated by the furrow method. From this, the row gradient and tentative length of run is determined. The original topography, field boundaries, and field size establish the approximate slope and length of run to be used.

The uniformity of distribution and water use efficiency depend on the smoothness and uniformity of the land surface. Seldom is the surface of the field sufficiently smooth and uniform in slope to permit efficient irrigation by the furrow method without removal or irregular-ities. Thus, land grading is a normal prerequisite to successful water application by this method.

Once the overall surface of the field has been graded to the design slope and direction, construction of the furrows in a manner to maximize distribution and application efficiency is of utmost import-ance. Slopes of 0.3 to 3.0 feet per 100 (percent slope) are recommended although slopes of 10.0 to 15.0 feet per 100 feet have been success-fully used (11). The length of the furrow is limited by the size of the field, but lengths of 300-600 feet are most common with an 800 feet maximum length specified by Soil Conservation Service engineers (19). Very long furrows can result in excessive water losses through deep percolation and the possibility of soil erosion occurrence near the upper end. The maximum length of the run should not exceed the dis-tance a stream of maximum allowable size will advance in one-fourth of the time required for the total irrigation (30).

Spacing of the furrows is usually governed by the proper spacing of plant rows with one furrow for each row. However, furrows must be sufficiently close together to permit water to move laterally to meet between adjacent furrows during the time allocated for application.

Row cross-sectional area plays a most important role since this affects the stream size, rate of intake, and rate of advance. This area must be sufficiently large to accommodate the largest initial irrigation stream introduced as well as to contain excess runoff resulting from storms. The shape of the furrow also affects water advancement and intake. Given two furrows of the same cross-sectional area, a flat-bottom furrow will advance water slower and with more intake than the conventional round-bottom furrow.

As can be seen by the above requirements, proper land preparation is a major factor in furrow irrigation effectiveness and efficiency, and serious consideration should be given to this subject in planning and designing a furrow irrigation project. After the earthwork and facilities for a furrow irrigation system have been completed, maintaining these is of utmost importance. Practices which promote long system life are using land planes annually, breaking ground with reversibile bottom plows, and using offset disk harrows.

IV. OCCURRENCE OF DROUGHT

The need for irrigation has been brought forcibly to the attention of farmers throughout the United States because of severe droughts that have, on various occasions, affected many of our agricultural areas. Although sufficient rainfall may be available for the growing of crops in normal years, costly experience has shown that short periods without rainfall have ruined crops which could otherwise have brought ample returns to the farmers. In only a few locations will precipitation fulfill requirements at all times to produce maximum yields. One of the most interesting characteristics of nature is its variation, its temporal and spatial changes. No patterns of uniformity are found in nature or in its rainfall. Rainless periods of two or more weeks frequently occur in humid-climate states (11). Humid-climate states are defined as those areas having more than 20 inches of rainfall annually (27).

The occurrence and effect of drought periods on the crops of the respective areas seem to be about the same whether the annual rainfall is 25 or 55 inches (26). This situation exists partially because rainfall of one-fourth inch or less does not wet the soil sufficiently to be beneficial to crops, and generally rainfall over three-fourths inch occurring in a short time period is lost as runoff. Then the range of one-fourth to three-fourths inch is the water which has the potential for use by the plants.

Therefore, areas which have high rainfall (55 inches or more per year) may not necessarily provide the most available water for plant use. It is factors such as this which must be taken into account when considering drought occurrence. Drought may be defined as occurring when evapotranspiration requirements exceed precipitation by the amount of available water in the soil.

CHAPTER II

REVIEW OF LITERATURE

I. VALUE AND HISTORY OF IRRIGATION

The value of irrigation cannot be fully realized without a review of its importance in history which parallels the development of civilization. Historians have had many disputes concerning the value of irrigation to civilization and its evolvement.

Many ancient civilizations lived and prospered on irrigated areas, while other civilizations have decayed and disintergated on irrigated regions. One factor is certain; civilization and its duration are dependent upon a permanent and profitable agriculture which relies on irrigation in many regions. Most persons who are well informed about irrigation are certain of its perpetuity as long as it is intelligently practiced (4).

The precise origin of irrigated agriculture is not known, but Egypt is usually considered its birthplace. Early rulers of Egypt were instrumental in developing the elaborate irrigation systems upon which their culture was based (4). More than 4000 years before the time of Christ, King Menes built a large masonry dam across the Nile near Memphis to divert water for irrigation. Queen Semiramis, ruler of Egypt about 4000 years ago, is said to have directed her government to divert Nile River water for irrigation. The inscription on her tomb reads in part:

> I constrained the mighty water to flow according
> to my will and led its waters to fertilize lands
> that had before been barren and without inhabitants.

Since her reign, irrigation and main canals in Egypt have been built and maintained by the national government.

Irrigation was well developed in Babylon prior to 2000 B.C. Hammurabi, King of Babylon about 2200 B.C., established regulations governing the maintenance and operation of irrigation ditches and provided severe penalties for farmers who did not use water in accordance with the rules. His regulations were included in the Code of Hammurabi which was recorded on a stone pillar unearthed in 1902. Part of the inscription read:

> I have made the canal of Hammurabi a blessing for the people of Shumir and Accad. I have distributed the waters by branch canals over the desert plains. I have made water flow in the dry channels and have given an unfailing perennial supply to the people .... I have changed desert plains into well watered lands. I have given them fertility and plenty, and made them the abode of happiness (3).

In China where reclamation was begun more than 4000 years ago, the success of early kings was measured by their wisdom and progress in water control activities. King Yu of Hsia-Dynasty (2200 B.C.) was elected king by the people as a reward for his outstanding work in water control. The famous Tu-Kiang Dam, still a successful dam today, was built in the Chin-Dynastity by a man named Mr. Li and his son. Today it provides irrigation water for about one-half million acres of rice fields (11).

The practice of irrigation in India antedates the historical epic by an indeterminate period. South of India, some of Ceylon's reserviors are more than 2000 years old. Writings from 300 B.C. indicate that the whole country was under irrigation, and very prosperous, because of the double harvests which the people were able to reap each year (11).

Frequent references in the Bible are made to irrigation, including the following passages from Genesis (2:10) and II Kings (3: 16-17):

> And a river went out of Eden to water the garden, and from thence it was parted, and became into four heads. And he said, Thus saith the Lord, Make this Valley full of ditches: For thus saith the Lord, Ye shall not see wind, neither shall ye see rain; yet that valley shall be filled with water, that ye may drink, both ye, and your cattle, and your beasts (4).

Early irrigation in America began more than 1000 years ago in Argentina, Peru, and other South American Countries. The Spaniards on their first entrance into Mexico and Peru found elaborate provisions for storing and conveying water supplies which had been used for many generations (4). In the southwestern United States, irrigation was practiced by the Indians long before Columbus discovered America, probably before the end of the seventh century. Remains of the early irrigation ditches may still be seen in Arizona and New Mexico (3).

About the end of the eighteenth century, Spanish padres from Mexico began the establishment of missions in Southern Arizona and California. The padres built small diversion dams, ditches, and conduits to bring water to the missions and to irrigate their gardens and fields (3).

Irrigation was practiced also by trappers, miners, and frontiersmen in many places in the West, although no effort was made to develop an agricultural economy based on irrigation until the Morman pioneers entered the Salt Lake Valley in July, 1847. Under the Mormons, irrigation was a cooperative undertaking with communities being located on the streams issueing from the mountains. Community ditches were constructed to serve both outlying agricultural areas and garden plots in the towns (11).

The development of irrigation from the above period to the present followed routes too numerous and varied to discuss here; however, the importance of irrigation in the world today is well stated by N. D. Gulhati of India (11):

> Irrigation in many countries is an old art-as civilization - but for the whole world it is a modern science - the science of survival.

The pressure of survival and the need for additional food supplies are necessitating a rapid expansion of irrigation in many parts of the world. Even though irrigation is of first importance in the more arid regions of the earth, it is for certain types of agriculture becoming increasingly important in humid regions (11).

II. SELECTION OF IRRIGATION METHOD

At the present time, many irrigation methods and variations of these methods are practiced in the United States. Irrigation methods vary in different locations according to soil, water supply, topography, crops, and customs. Some of the methods used today are discussed below.

Surface Irrigation

Free Flooding. Free flooding permits the water to flow freely over a field by gravity, and it is one of the earliest and most popular irrigation methods. Head ditches placed at intervals according to ground slope, soil type, and available water bring the water across the field at right angles to the direction of the natural slope. The water is then let out of these ditches at intervals to allow uniform distribution over the land without undue overlapping. This method is well suited to crops of grain, grass, and other close-grown crops; but it is not adaptable to row crops (7).

Border Strip Irrigation. For the border strip flooding method, a field is divided into a series of strips by a series of borders (low flat dikes) run down the predominant or any other desired slope. To irrigate, water is turned onto the head of the border; it advances - confined and guided by two borders - in a thin sheet toward the lower end of the strip (15). This method is well suited for forage crops since large areas can be irrigated with a relatively low investment. This method when properly designed, affords a very high irrigation efficiency with low labor requirements.

Check Flooding. The check-flooding method consists of running comparatively large streams into relatively level plots surrounded by levees. This method is well suited to very permeable soils which must be quickly covered with water in order to prevent excessive losses through deep percolation near the supply ditch (11). This method is well suited to irrigation of forage crops or grain.

A variation of the check-flooding method is known as basin flooding. It is accomplished by the construction of a basin around a small area. This method is usually limited to use in orchards where a basin is constructed around a tree and then flooded (15).

Corrugation and Furrow Irrigation. Furrows and corrugations are essentially similar; each being an irrigation method by which water is conveyed to the plant through long, small capacity channels dug or pressed into the soil at regular intervals (7). Furrows are used on flat slopes or on the contour and have a larger cross section. Corrugations are furrows used for steeper slopes, and they have a smaller cross section.

The furrow method of irrigation is universally used with row crops. Furrow spacing is determined by the proper spacing of plant rows, one irrigation furrow for each row. The lower ends of the furrow terminate in a waste ditch to provide for drainage of excess water (15).

Sprinkler Irrigation. The sprinkler system of irrigation offers uniform distribution of water to the land under cultivation by means of a spray, with distribution similar to rainfall (15). The sprinkler method is best suited for land with rough topography where land grading would be too costly, impractical, or undesirable. The main disadvantages of sprinkler irrigation are the high initial investment cost for equipment and high labor requirements for some installations.

Some advantages of sprinkler irrigation over other methods point to the increased use of this system today. Water application is more uniform over a given area. Fertilizer may be injected into the system and applied with the water. Also most of the land area is available to crops since little land is lost to ditches and surface structures.

Sub-Surface Irrigation

In a few localities, natural soil and topographic conditions favor the application of water to soils directly under the soil surface, a practice known as sub-irrigation (11). Two distinctly different sub-irrigation systems are used today (7).

Continuous Flow System. This system is suitable to very deep sandy loam soils and peat-type soils. Ditches 3 to 4 feet deep and 1000 to 2000 feet long are kept flowing. Water seeps into the open subsoil and, by capillary action, rises to the surface.

Intermittent Flow Irrigation - Drainage System. This system consists of a network of drain-irrigation channels or pipes spaced 100 to 300 ft. apart in a grid pattern. Spacing depends on permeability of the subsoil and the topgraphy. This method is used on level land with a slope not exceeding 2 percent.

III. SELECTION OF IRRIGATION METHOD

Ideally, a farm irrigation system must be capable of applying an adequate amount of water uniformly and efficiently. A successful system is one that provides economic benefits in terms of crop yield and crop quality while assuring the continued productivity of the land and using water without excessive loss in either quality or quantity. It is a system that not only has the capacity to meet crop water requirements in high use periods, but also has sufficient flexibility to allow for different soils, varying water use rates throughout the growing season, and special purpose applications such as freeze control, leaching, and high temperature control. Finally, recognition of today's costs for labor and for alternative capital investments that replace labor or improve system performance (24), the irrigation system must be easy to operate and maintain.

Just as several irrigation methods are available, just as many arguments are advanced on the pro's and con's of each irrigation method. Unfortunately, opinions are often based on limited local experience where a method has been used which was completely unsuitable to existing conditions; and some other method might have been better adapted. Success is often taken for granted and receives little publicity; on the other hand, one who fails in a certain endeavour is likely to broadcast the shortcomings of a method rather than question its merits (7).

Every modern irrigation method has both advantages and disadvantages, and each has a definite place in an irrigation system. The prospective irrigator must make appropriate evaluations and choose the method best suited to individual local conditions. During the planning stages, some of the factors which should be studied and evaluated for an irrigation project are as follows (3):

1. Type of project and general plan of irrigation works.
2. Location, extent, classification and soil types of irrigable lands.
3. Irrigation requirements for profitable crop production.
4. Water supplies (water rights) that can be secured for project use.

5. Irrigable areas that can be economically supplied with water.
6. Types and locations of necessary irrigation works.
7. Needs for immediate and probable future drainage.
8. Cost of storage, irrigation, power, and drainage features.
9. Method of financing the construction of project works.
10. Desirable order of construction and development.
11. Probable annual cost of water.
12. Cost of land preparation and farm distribution systems.
13. Feasible crops, costs of crop production, and probable crop returns.
14. Labor available.

The best method to use in a particular case depends on topography, character of the soil, kind of crop, amount of water available, work schedule, cost, and the owner's desires or experience. Each irrigation method has advantages and disadvantages which suit it to one or more specific situations. A careful evaluation of each method is most desirable in the selection (Table I). In order to illustrate this point, some of the most common methods will be listed with specific advantages and disadvantages of each system.

Sprinkler Irrigation

Advantages

1. Less water is required.
2. Less labor is needed in preparing the land for irrigation.

TABLE I

COMPARISON OF IRRIGATION METHODS

Method	Adapted to Soils	Slope %	Crops
Ordinary flooding	All	Up to 12	Close Growing
Border flooding	All	Up to 3	Legumes Grains
		Up to 6	Pasture
Contour check flooding	All except very heavy	Less than 2	Close Growing
Basin flooding	All except very heavy	Less than 2	Orchards Close growing
Furrow	All except very permeable	Up to 8	Row crops Orchards
Corrugation	All except very permeable	Up to 12	Close growing
Subirrigation	All except very permeable	Less than 2	All
Sprinklers	All	All	All

3. It is better adapted to hilly, unlevel land, and some light soil types.
4. More efficient in applying the correct amount of water to some soil types.
5. Can be used to distribute liquid manure and soluble commercial fertilizers.
6. Different capacity sprinkler outlets adapt themselves well to different soil types often existing along main and lateral sprinkler lines.
7. Can be used to prevent freeze damage.
8. System can be designed and installed quickly.
9. Systems can be portable.

Disadvantages

1. High initial investment costs.
2. High labor required to set up, move, and maintain system.
3. High power costs to maintain proper water pressure.
4. Evaporation rates may be high in some cases.
5. Possibility of disease due to wetting of plant foliage.
6. Chemicals used for insect control may be removed from plants.
7. Spray patterns may be affected by the wind.

<u>Furrow and Corrugation Irrigation</u>

Advantages

1. Can be applied to all except very permeable soils.
2. Relatively low initial investment for equipment.
3. Low labor and pumping costs.
4. In some cases, more uniform application of water.

5. Flow of water is easily regulated.
6. Lower evaporation loss than sprinkler.
7. High application efficiency.
8. Water is not applied on foliage.

Disadvantages

1. Flow must be carefully regulated to maintain uniform application.
2. Furrows create problems with mechanized harvesting machinery.
3. Land must be graded to control flow of water.
4. Danger of erosion present.
5. Excessive water loss in highly permeable soils

<u>Flood Irrigation</u>

Advantages

1. Can be used on all soils.
2. On suitable land, irrigation cost is low; pumping costs are usually minimal.
3. Very little land preparation on suitable areas.

Disadvantages

1. Low application efficiency.
2. High labor requirements.
3. More land preparation necessary.
4. Requires large water supplies.
5. Excessive evaporation.

Sub-surface Irrigation

Advantages

1. Minimum evaporation losses.
2. No leaching.
3. Low labor costs in irrigation.
4. High efficiency of application.

Disadvantages

1. High costs of installations.
2. Limited to special soil conditions.
3. Poor water distribution.
4. Water having high salt content cannot be used.
5. Deep rooted crops such as deciduous orchard trees and citrus trees generally cannot be sub-irrigated.

As can been seen by the preceding discussion, each system has many advantages and disadvantages, but generally one method will fit a given situation much better than one or more of the other methods. One common mistake made by many potential irrigation prospects is to believe that one method of irrigation can be applied to all areas on their particular farm. This is not always true. Careful consideration should be given to each individual situation. The best method for one location may not be the best for another. That method of irrigation which can most economically and efficiently distribute the required quantity of water uniformly is generally the best method.

Another important aspect in the design of an irrigation system is the selection of equipment to use for a particular irrigation method.

The individual components of an irrigation system are the power supply, the pump, and the pipe. These three components should be matched to each other according to the design criteria of the irrigation system. The size of the pump is determined by the total head and the rate of pumping in the irrigation system. The size of the power source is determined by the discharge rate, pumping pressure, and the efficiency of the pump. The size of the pipe is determined, not only by the distance the water is to be carried, but also by the size of the pump and the power source. When the components of an irrigation system are properly matched, the overall results are increased efficiency and lower costs in operation.

IV. PROBABILITY OF DROUGHT

Agricultural drought is a situation with which most farmers of the world are familiar. But not many people fully understand the conditions associated with and accompanying drought. The word drought can be used to describe a wide range of conditions. Some of these conditions are: *permanent drought* where the precipitation is never sufficient to meet crop needs as expressed in terms of potential evaporation and transpiration; *contingent drought* resulting from variations in precipitation from year to year; *seasonal drought* where inadequate amounts of precipitation occur in one season; and *invisible drought* which is the case of a borderline inadequacy of rainfall, not quite sufficient rainfall to satisfy the crop needs from month to month, and which shows up only in reduced yields at the end of the year (15).

Drought is the single largest cause of all insured crop losses in the United States. Losses due to drought are almost three times as great as the next greatest cause (Table II).

In the humid areas of the United States, contingent drought and invisible drought are farmers' main concerns related to irrigation. The easily recognized and severe droughts, often many years apart, do not reduce average yearly crop yields as much as the unrecognized invisible droughts which occur year after year, especially when they occur at critical times in the growth of plants. Rainfall may appear to be adequate, but it is usually poorly distributed. Because of this, the farmer often harvests only part of the crop from year to year that he could harvest if adequate water were available when it was needed.

Farmers face many risks and uncertainties in operating their businesses. One of the most important of these uncertainties is the variation in crop yields that result from wide yearly variations in quantity and distribution of crop-season rainfall. Therefore, farmers are faced with uncertain conditions regarding production planning and crop yields. This condition of uncertainity results in inefficient use of agricultural resources. If some of these uncertainties could be reduced or eliminated, the farmer's risk of lowered production would also be reduced. Consequently, when information on the probabilities of various outcomes or occurrences of a given drought level becomes available for a given location, a major uncertainity in farm management would be reduced (14).

C. H. M. van Bavel (17) has carried out much work in the area of

TABLE II

Causes of FCIC Losses 1948-1962

Cause	Percent of all losses*
Drought	39.1
Excess moisture	14.0
Insects	10.9
Hail	10.2
Freeze	10.0
Wind	5.6
Disease	4.8
Other	5.4

*Taken from Annual Report 1963 Federal Crop Insurance Corporation.

agricultural drought and follows the procedure used by most scientists in devising a drought index which can be used to predict the probability of drought for a given area. The purpose of the drought index is to determine how many drought days occurred in past seasons, and from this information, to predict what can be expected in future seasons on a probability basis. With an estimate of the extent and frequency at which droughts are expected to occur, the farmer can place much more faith in his planning and expected yields in the future.

The first step in indexing drought is to define drought conditions in a workable manner. Agricultural drought has been defined in the past in terms of inadequate rainfall for optimum plant growth. This means of characterizing drought has been used because rainfall data are readily available, and because drought is largely dependent upon rainfall during the cropping season (14). This method of characterizing drought, however, does not take into account some plant and soil conditions which determine the extent of injury to a plant from drought. Rooting characteristics of a given plant and the available water holding capacity of a given soil have a direct bearing upon the injury of a plant under drought conditions. Drought should be defined in a way which takes into account these factors rather than basing drought directly on amount of rainfall.

C. H. M. van Bavel's method of indexing drought (17) takes into account not only rainfall data, but also moisture losses due to evapotranspiration (evaporation from the soil plus transpiration losses from plant leaves). The method utilizes the principle that the soil to a depth of the effective rooting zone of the crop is considered as as a moisture reservoir. The capacity of this reservoir varies with the water holding capacity of the soil and the root zone of the crop being used. Moisture from the reservoir is reduced by evapotranspiration. The moisture level in the reservoir is increased by rainfall or irrigation.

Since no record is available of moisture in the soil, a base condition must be established from which to start. Usually sufficient moisture is available during winter and spring months, and drought calculations are not needed for these periods. In most areas, drought calculations can be started in April when the soil is saturated and continued until a killing frost occurs. The beginning point for this method of drought indexing is to establish a moisture base for a given soil. This is accomplished by determining the amount of water which can be retained by the soil in the root zone. The depth and texture of the topsoil and the depth and texture of the subsoil in the root zone can be used in the determination of water holding capacities. When this base moisture supply has been established, the addition of rainfall and subtraction of evapotranspiration is carried out in a bookkeeping manner so that the base moisture supply can be calculated from day to day. An example is shown in Table III.

Some slight problems are associated with rainfall and evapotranspiration data. A record of daily precipitation over at least twenty years is necessary in order to predict daily averages for calculation periods. In some instances these records are not available or they may be available for brief periods only. With a record of several years' precipitation data, a study of the frequency distribution of drought

TABLE III

Example of Drought Day Calculations as Inches of Moisture

Day	Moisture Base	Precipitation	E.T.[a]	New Moisture Base
0				2.00
1	2.00	0	.15	1.85
2	1.85	0	.15	1.70
3	1.70	1.0	.15	2.00[b]
4	2.00	0	.15	1.85
5	1.85	0	.15	1.70
6	1.70	0	.15	1.55
7	1.55	0	.15	1.40
8	1.40	0	.15	1.25
9	1.25	0	.15	1.10
10	1.10	0	.15	.95
11	.95	0	.15	.80
12	.80	0	.15	.65
13	.65	0	.15	.50
14	.50	0	.15	.35
15	.35	0	.15	.20
16	.20	0	.15	.05
17	.05	0	.15	0[c]
18	0	0	.15	0[d]
19	0	1.5	.15	1.35
20	1.35	0	.15	1.20
21	1.20	.45	.15	1.50
22	1.50	0	.15	1.35

NOTE: Average daily evapotranspiration has been assumed to be 0.15 inches per day, and the beginning moisture base for the crop root zone is 2.0 inches.

a = Evapotranspiration.

b = Moisture base total never exceeds base amount.

c = A drought day although some water (0.05) was available for plant use.

d = Drought day.

day occurrences, and thus predictions for future periods of time, can be made.

Evapotranspiration is another factor in the drought index calculation which must be determined accurately in order to give a valid drought index.

Several methods have been developed for the purpose of determining evapotranspiration. Blaney and Criddle developed an empirical formula in 1945 giving the relationship between mean temperature, length of growing season, monthly percent of daytime hours, and consumptive use of water (31). Their formula is $U=KF=\Sigma kf$ where U is estimated evaporatanspiration in inches for the growing season; K is empirical consumptive use coefficient; and F is the sum of monthly consumptive use factors. In evaluating kf, f is the monthly consumptive use factor where $f = tp/100$. Here, t is the mean monthly air temperature in degrees Fahrenheit and p is mean monthly percent of daytime hours and k is monthly consumptive use coefficient. Mean monthly temperatures and percent of daytime hours for each month can be determined from Weather Bureau records.

In 1948, Penman (11) developed a formula for evapotranspiration, in combination with Dalton's law for evaporation of water. Penman has the most complete theoretical approach based on radiant energy; it includes corrections for wind speed, relative humidity, sunshine percentages; and it uses a reflection coefficient. His formula for representing the potential evapotranspiration is $ET = \frac{\Delta H + 0.27\ Ea}{\Delta - 0.27}$ where values of H and Ea are given by $H = Ra\ (1-r)\ (0.18 + 0.55n/N) - \sigma Ta^4$

$(0.56 - 0.92\sqrt{e_d})\ (0.10 + 0.90\ n/N)\ Ea = 0.35\ (e_a - e_d)\ (1 + 0.0098U_2)$.

The symbols for this formula follow:

H = Daily heat budget at surface in mm H_2O / Day.

Ra = Mean monthly extra terrestrial radiation in mm H_2O per day.

r = Reflection coefficient of surface.

n = Actual duration of bright sunshine.

N = Maximum possible duration of bright sunshine.

σ = Boltzmann constant.

σTa^4 = mm H_2O / day.

e_d = Saturation vapor pressure at mean dew point mm Hg.

E_a = Evaporation in (mm) H_2O / day.

e_a = Saturation vapor pressure at mean air temperature in mm Hg.

U_2 = Mean windspeed at 2 meters above ground (miles / day).

E_T = Evapotranspiration in mm H_2O / day.

Δ = Slope of saturated vapor pressure curve of air at absolute temperature Ta in °F (mm Hg / °F).

The principal limitation of the Penman approach is the lack of sufficient weather measurements and data for most localities. The difficulty of developing useable statistical confidence levels for predicted H values is another limitation.

Several other methods are available for determining evapotranspiration (Hargreaves method, Lowery-Johnson method, and Thornthwaite method (36)) but the two methods previously described are the ones most commonly used. The Penman method is most commonly used in Tennessee due to the excessive amount of data required for some of the other methods.

Once the precipitation data and the evapotranspiration data for an area have been collected, calculating the drought index is a relatively simple matter. Rainfall or irrigation is added to, and evapotranspiration is subtracted from the moisture base according to the two rules: (1) results are never to exceed the base amount; and (2) results will never be less than zero. All days on which a result of zero is obtained are labeled as drought days.

V. SOILS SUITABLE FOR IRRIGATION

A soil survey is essential to irrigation planning. It is the basis for determining if the soils are irrigable and is used by the planner to fit the system to the soil. The location and extent of soils that differ widely must be considered in deciding how an area can be sub-divided, if necessary. The most important soil characteristic is its ability to absorb and retain water. Other soil conditions that affect planning of irrigation should be noted, such as high water table, restrictions to drainage, erosion hazard, and salt content (19).

The ideal soil for irrigation is one of medium or fairly fine texture and of deep, mellow, open structure, allowing easy penetration of roots, air and water, and having free drainage yet good water holding capacity. This ideal combination of soil characteristics most often exists in the more recently deposited alluvial soils on the flood plain of streams or on alluvial fans. The soils of medium texture (fine sandy loams, very fine sandy loams, loams, silt loams, clay loams, and silty clay loams) are commonly most productive and most desirable for development under irrigation. Neither sandy soils nor heavy clays are generally desirable. Sandy soils do not hold sufficient water, are relatively infertile, and have a tendency to blow; the clays do not drain well, are hard to plow and cultivate, and are less productive under average farming practices (35).

Infiltration and the available water holding capacity are two of the most important characteristics of a soil to consider for irrigation purposes. Infiltration is the passage of water into the soil surface (27). Infiltration is important because water must pass into the soil surface before it will be available for use by the plants. High infiltration rates also reduce surface runoff and prevent erosion. Infiltration is dependent upon: (1) the size of the soil particles, (2) aggregation between individual particles, and (3) the arrangement of soil particles and aggregates.

The available water holding capacity of a soil is a measure of the amount of moisture available for plant use. A high available water holding capacity for a soil indicates that the soil can supply a higher amount of moisture to the plants than a soil which has a low available water holding capacity.

Soils which have a high available water holding capacity are those soils of high silt and fine textured sand content. Soils having low available water holding capacities are those soils containing high amounts of clay or coarse sand. The mean available water holding capacity of Tennessee soils is 0.203 inches of available water per inch of soil (9).

CHAPTER III

PROCEDURE

I. IRRIGATION WITH WATER

Site Selection

Selection of the site for this research was limited to those areas suitable for furrow irrigation as discussed in Chapter Two under the section on selection of the irrigation method.

Two plots of approximately one acre each were selected from a graded bottom land on the West Tennessee Experiment Station at Jackson, Tennessee. This field had been graded in 1962 (Sewell and Hazelwood, (20)), and much of the settling due to the grading operation had occurred prior to this research. The plots selected were approximately 750 feet long and 100 feet wide. The average design slope of the irrigation furrows was 0.36 percent. Each plot (Figure 1) consisted of 18 rows of corn in sub-plots of six rows each. Each sub-plot (Figure 2) was separated by six rows of corn which were not included in the test area. The research plots are located alongside the Forked Deer River which can provide an ample water supply for irrigation purposes during dry periods.

Soil Types and Properties

The soils of the experimental irrigation plots are predominately

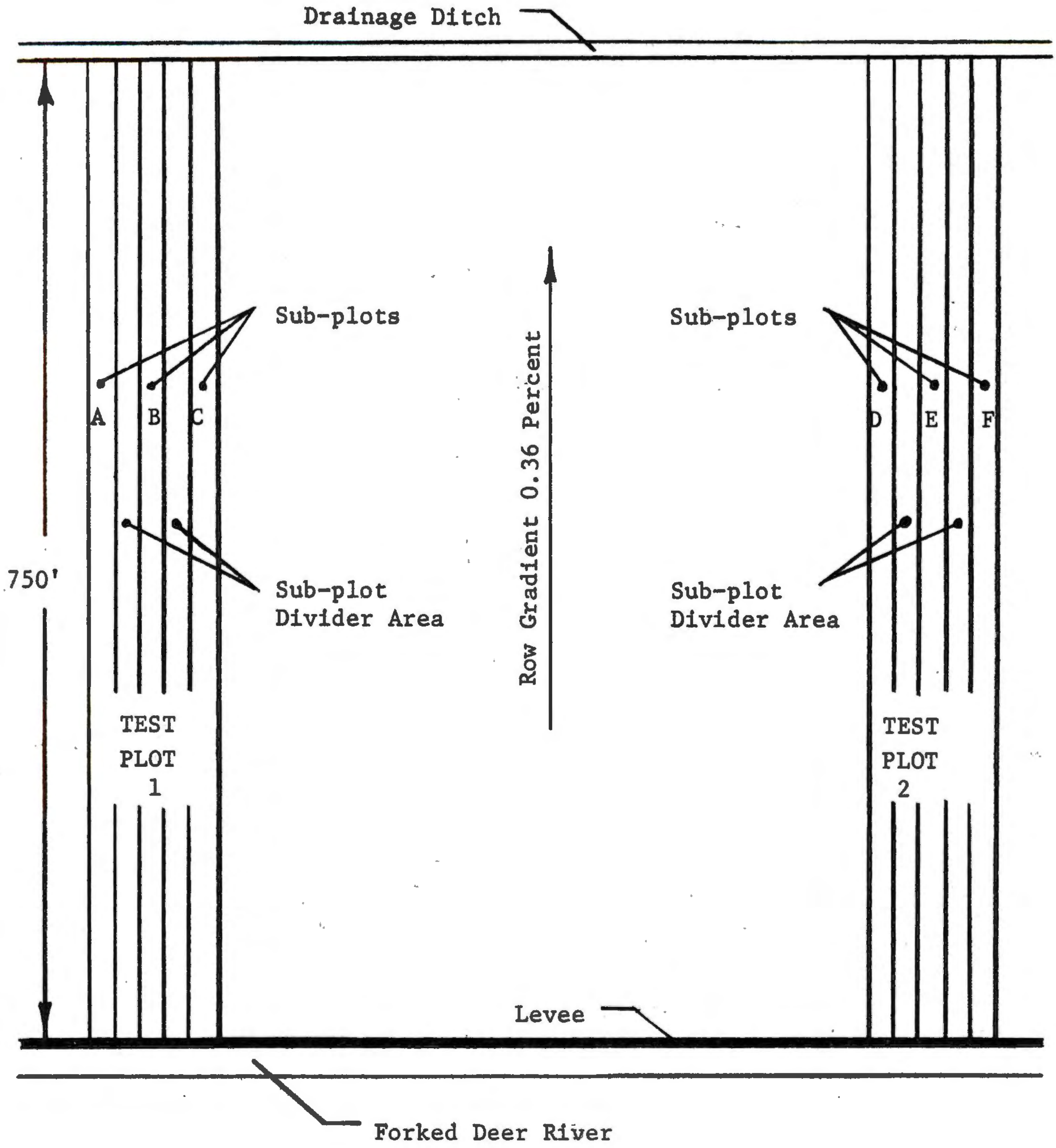
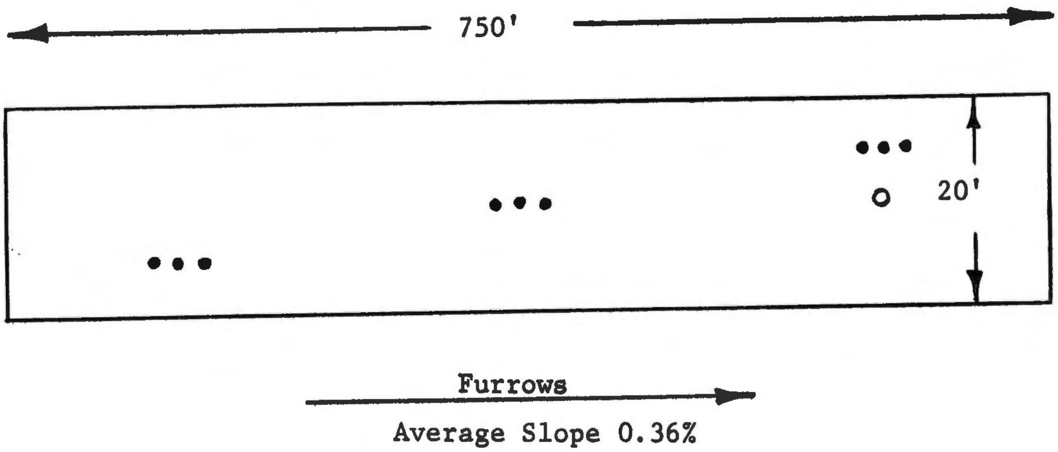


Figure 1. Layout of Test Plots at the West Tennessee Experiment Station.



• Soil moisture access tubes

o Tensiometer

Figure 2. Locations of soil-moisture tubes and tensiometers on each sub-plot.

of two types. One plot consists entirely of Waverly silt loam, and the other plot is comprised almost equally of Waverly silt loam and Collins silt loam. Although the area has been graded to improve surface drainage, almost no mixing of the soil types has occurred except along the boundaries of the two soils.

Waverly silt loam is a poorly drained gray soil found on many nearly level bottom lands in West Tennessee. Permeability is moderately slow and the infiltration rate is moderately high. The available water holding capacity if 0.290 inches of available moisture per inch of soil. The surface layer of this soil varies from one to twenty feet thick (31).

Yields of corn and cotton are generally small on this soil type due to the excessive water. When good drainage is provided, this soil will produce reasonably good yields of corn or cotton. Good drainage of the area containing the irrigation plots has contributed greatly to the use of this land for corn production.

Collins silt loam is a nearly level, moderately well drained soil found on many bottom lands of the area. Permeability is moderate in the surface layer and infiltration is moderate. The mean available water holding capacity is 0.323 inches of available moisture per inch of soil. Corn production on this soil is good with excellent response to good management (31).

Equipment and Irrigation Procedure

Water was supplied to the irrigation plots by a four-inch by four-inch centrifugal pump connected by direct drive to a four-cylinder gasoline engine. The exhaust primed pump and engine were mounted on wheels for ease of transport and manueverability. The engine-pump combination had a maximum design continuous performance capacity of 500 gallons per minute at a head of approximately 170 feet and pumping efficiency of 68 percent.

The intake line from the water supply to the pump consisted of three sections of six-inch aluminum pipe ten feet long. The sections were connected using dresser couplings. The discharge line from the pump consisted of a six-inch diameter flexible hose 20 feet long connected to a six-inch diameter gated aluminum pipe. The gates in the pipe were equipped with adjustable openings which permitted control of the flow rate from each gate (Figure 3). The gates were located on 40-inch center spacings.

Soil moisture measurements were made for each plot immediately prior to irrigation according to procedures outlined in the following section of this chapter. As soon as irrigation was indicated necessary by one or more of the soil moisture methods, irrigation was started and water was supplied to the plot at or near the maximum capacity of the pump until water reached the lower end of the furrows, usually after about one to two hours of irrigation. As soon as water reached the lower end of the plots the pump speed was reduced and the gates in the pipe were adjusted to maintain flow through the furrow with a minimum of tail water loss (Figure 4). The flow rate from each gate was recorded by volumetric measurement for each pumping rate for application determinations. Irrigation was continued until the upper layer of the soil was saturated, usually after four to six hours of

Figure 3. Irrigation flow from six-inch gated aluminum pipe.

Figure 4. Water flowing from the gated pipe and down the furrow.

irrigation. Twenty-four hours after irrigation had stopped, soil moisture measurements were taken again. The twenty-four hour period allowed excess water to drain from the area which permitted a more accurate determination of water application efficiency.

Soil Moisture

The soil moisture of the test plots was measured by three methods, (1) a neutron scattering soil moisture meter equipped with a depth probe, (2) tensiometers, (3) gravimetric methods.

Aluminum soil moisture access tubes two inches in diameter and 36 inches long were installed in each of the irrigation plots for use with the neutron scattering equipment. The principle of the neutron method is based upon measurement of the number of hydrogen nuclei that are present in a given volume of soil. The number of hydrogen nuclei is a direct function of the number of water molecules in the same volume of soil. A source of fast neutrons is introduced into the soil by means of a sub-surface probe lowered into the access tube at pre-determined levels. A measurement is then made of slow neutrons produced when the fast neutrons collide with nuclei of the soil. The source of fast neutrons is usually an encapsulated Ra-Be pellet enclosed in the probe. The count of slow neutrons is transmitted to a scaler which gives a count per unit of time (27).

The tubes were installed in series of three to a location within the plots (Figure 2). The purpose of this installation method was to reduce as much as possible moisture reading fluctuations irrevelant to existing moisture conditions of the soil. Readings were taken at the

0, 6, 12, and 18 inch levels below the soil surface at all locations. All values for each location were averaged to obtain moisture level values for that given location. Summaries of the data are given in Appendix A.

Three tensiometers were installed in the corn rows at a depth of 10 inches near the lower end of each plot (Figure 2). This permitted use of the tensiometers to determine soil moisture values away from the initial water supply to the plots. As the tensiometer readings approached one-third atmosphere tension, the observer could determine that soil moisture at the lower end of the field was nearing the desired application level.

Corn Yields

Corn yields were determined on each irrigation plot and four adjacent non-irrigated plots. Each plot consisted of three sub-plots of six rows (Figure 1) of which the center four rows were harvested for silage yield determinations. The plots were harvested in the conventional manner using a corn silage chopper. Non-irrigated plots on each side of the irrigated plots were harvested in the same manner. The yield from each plot was weighed and converted to equivalent green-matter tonnage per acre yield. Yields were determined on both irrigated and non-irrigated plots for comparison purposes.

In addition to tonnage yields, three samples of silage from each plot were collected and analyzed to determine silage quality as influenced by moisture content. Each of the samples was converted to moisture content on both wet and dry bases.

II. IRRIGATION WITH DAIRY MANURE SLURRY

Site Selection

The area selected for this research study was the University of Tennessee Cherokee Dairy Farm at Knoxville, Tennessee. This site was selected because of the existing liquid manure facilities at this location and previous research which had been carried out on liquid manure at this location (Sewell, (28) and Barker and Sewell, (1)).

The irrigation plot selected was located approximately 100 yards from the liquid manure storage tank which served as the source of the dairy manure slurry (Figure 5). The plot was approximately 500 feet long by 120 feet wide. The plot was graded in 1972 to remove irregularities in slope and to reduce the overall slope of the plot. The average slope on the plot after grading was 1.31 percent which is greater than that desired for this type of irrigation. The entire plot was furrow irrigated with the dairy manure slurry and soil samples were taken at random within the plot after each irrigation for moisture calculations.

Soil Type and Property

Etowah soil is a moderately deep to very deep, well drained soil found in areas of East Tennessee on stream terraces of medium height. Etowah soils have a dark-brown or brown friable silt loam to a reddish brown to yellowish-red friable silty clay loam surface stratum. The subsoil is reddish-brown or brown to yellowish-red or red friable to firm silty clay loam or firm silty clay. Most of the Etowah soils are found on sloping and gently sloping terraces. The surface soil varies from dark brown to brown and from silt loam to loam in texture (30).

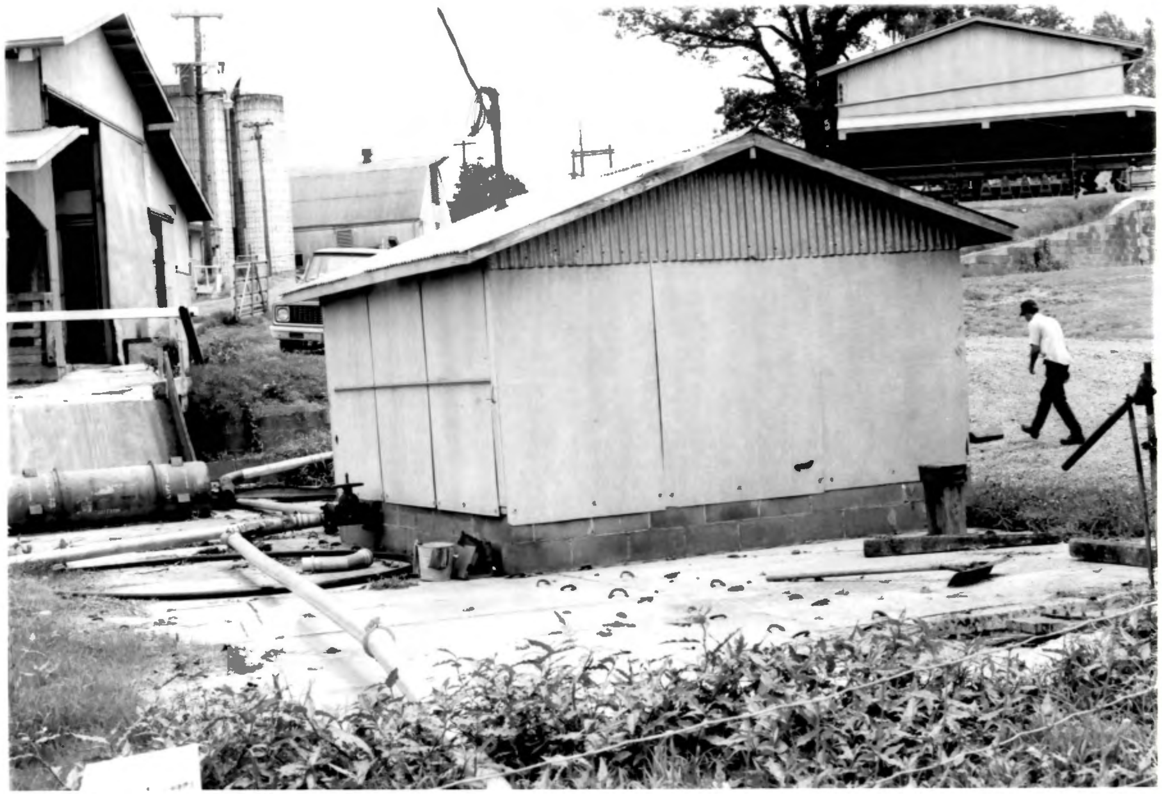


Figure 5. Manure Slurry Pumping Facility: Pump house located on manure tank and irrigation line (arrow) from pump house to plot.

The topsoil on the test plot for this experiment ranged from 6 inches to 11 inches in depth. The furrow grade was altered by grading to a more uniform and less steep grade in the spring of 1972. The maximum cut was approximately 6 inches and the maximum fill was 8 inches. The maximum cut occurred in an area where the average depth of topsoil was 9-10 inches; therefore, no areas of subsoil were exposed. This grading operation reduced the flow rate through the furrows during irrigation and allowed the water to infiltrate more rapidly than prior to grading.

Equipment and Irrigation Procedure

The dairy manure slurry was supplied to the irrigation plot by a three-inch by three-inch open impeller centrifugal pump driven by a 25-horsepower electric motor. The pump used in this research normally empties the tank through an irrigation line to a giant nozzle sprinkler.

A four-inch aluminum irrigation line was connected at the pump, and it carried the manure slurry to the irrigation plot where six, twenty-foot sections of four inch gated aluminum pipe delivered the manure to the furrow. The gates in the pipe are two-inch long, oblong, adjustable openings. However, due to the nature and consistency of the manure slurry, the gates were operated at all times fully open. This was necessary because of the fiber content (straw and hay) of the slurry (Figures 6 and 7). The rate of application was controlled by a gate valve located on the discharge side of the pump. The pump discharge was regulated to approximately 200 gallons per minute, the minimum discharge for this pumping system. This was due to excessive

Figure 6. Manure slurry flowing from gated pipe into furrow; Note the straw and fibrous matter protruding from the gate in the pipe.

Figure 7. Manure slurry in the furrow immediately after pumping had stopped.

TABLE IV

Application Rates and Irrigation Efficiency on West Tennessee Experiment Station Test Plots

Date	Test Plot[1]	Irrigation Application	Irrigation Efficiency
July 16, 1970[2]	1	2.88 In.	68[4]
July 17, 1970[2]	2	3.54 In.	87[4]
August 4, 1970	1	2.92 In.	66[4]
August 5, 1970	2	2.58 In.	91[4]
July 13, 1971	1	3.85 In.	72[4] 70[5]
July 14, 1971	2	2.70 In.	86[4] 84[5]
August 22, 1973	1	3.79 In.	68[5]
	2[3]	-----	--

[1]Refer to Figure 1.

[2]Data collected by Robert S. Pile (former Graduate Student in Agricultural Engineering).

[3]Plot two was not irrigated because of a very poor stand of corn.

[4]Moisture determined using Neutron Scattering Soil Moisture Meter.

[5]Moisture determined using Gravimetric method.

being irrigated (27). The flow rate and application time were used to obtain an application rate. The application rate is determined by calculating the amount of water applied to the irrigated area (Flow rate per gate in GPM times number of gates times minutes of application) and converting this amount to inches of water per acre using the formula Acre Inches = $\frac{\text{gallons applied}}{27,154}$.

Corn Yields

Corn yield on the irrigated plot was determined by harvesting four subplots which were 50 feet long by 6.33 feet (2 rows) wide. Yields were converted to equivalent tonnage green matter per acre. Two sub-plots outside the irrigation plot but in the same area were also harvested as control plots. All harvesting was by hand cutting, and the corn was weighed in the field using a portable scale and canvas sling mounted on a pipe tripod.

CHAPTER IV

ANALYSIS OF DATA

I. IRRIGATION WITH WATER

Soil Moisture

Soil moisture data were collected on the test plots in order to determine the amount of moisture added to the soil by irrigation and also to determine the irrigation efficiency.

The neutron scattering soil moisture meter gave a count of slow neutrons which was converted to pounds of water per cubic foot of soil using a graph-type chart furnished with the equipment (27). By this method, the amount of moisture added to the soil was determined by taking moisture readings before and after irrigation (See Table IV).

Corn Silage Yields

Yields of corn silage from the test plots and from the check plots at the West Tennessee Experiment Station were determined in order to obtain an estimate of effects of irrigation on corn silage yields. All harvesting on the test plots was by conventional means using a tractor pulled two-row silage chopper. All yields were converted to equivalent greenmatter tonnage per acre in the field using portable scales to weigh the wagons containing sub-plot yields. The corn silage yields from the test plots and check plots are given in Table V.

TABLE V

Summaries of Corn Silage Yields at West Tennessee Experiment Station

Date	Plot	Yield[1]	Difference[2]
August 27, 1970[3]	Irrigated 1	14.2[4]	+2.1
	Non-irrigated 1	12.1	
	Irrigated 2	12.6	+1.2
	Non-irrigated 2	11.4	
August 25, 1971	Irrigated 1	15.3	+0.4
	Non-irrigated	14.9	
	Irrigated 2	16.0	-1.0
	Non-irrigated 2	17.0	
GROWING SEASON 1972		NOT IRRIGATED DUE TO ADEQUATE RAINFALL	
August 31, 1973	Irrigated 1	8.6	+1.0
	Non-irrigated 1	7.6	
	Irrigated 2[5]	----	---

[1] Tons green-matter per acre.

[2] Irrigated yield minus check plot yields in tons per acre.

[3] Data collected by Robert S. Pile (former graduate student in Agricultural Engineering) from the same test plots.

[4] Average yield from three sub-plots within the test plot.

[5] Test plot two was not irrigated because of poor corn stand on the plot.

A statistical analysis was applied to the corn silage yield from the test area for the three-year period in which this research was conducted. The results of these analyses can be seem in Table VI. In 1970, the analysis indicated a significant difference in yield due to irrigation and a significant difference in replications which indicates that soil types influenced the corn yields. In 1971 and 1973, no significance was found due to irrigation. Therefore, the treatments and error term were pooled. These two analyses attribute a difference in corn yield to the soil type also.

II. IRRIGATION WITH DAIRY MANURE SLURRY

Soil Moisture

Soil moisture measurements were made on the test plots prior to irrigation and again 12-24 hours after irrigation was completed. All moisture measurements were by the gravimetric method. A total of eight soil samples were taken on the test plot at each irrigation. A summary of test data appears in Table VII. On July 9, 1971 the difference between the average of soil moisture readings before and after irrigation was 8.5 percent. Irrigation increased the moisture in the soil from 13.7 percent to 22.5 percent. The low application efficiency was due to short row lengths and a greater than desirable furrow grade. This situation created a large amount of tailwater which greatly lowered the irrigation efficiency.

On June 26, 1972, the irrigation application increased the moisture level but the amount of increase could not be calculated due to rain

TABLE VI

Analysis of Variance for West Tennessee Experiment Station Corn Silage Yields

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F
		August 26, 1970		
Treatment	1	8.17	8.17	68.08[1]
Replications	5	3.97	0.79	6.58[2]
Error	5	0.61	0.12	
Total	11	12.74		
		August 25, 1971		
Replications	5	5.88	1.17	4.05[3]
Pooled	6	1.74	0.29	
Total	11	7.62		
		August 31, 1973		
Replications	5	9.0	1.80	2.54[4]
Pooled	6	4.0	0.67	
Total	11	13.00		

[1]Significant at the 0.01 level of probability.

[2]Significant at the 0.05 level of probability.

[3]Significant at the 0.10 level of probability.

[4]Significant at the 0.25 level of probability.

TABLE VII

Summary of Soil Moisture Data From Cherokee Dairy Farm Test Plots

Date	Moisture Percent			
	Sample Numbers	Before[1,2]	After[3]	Moisture[4] Added
July 9, 1971	1	15.5	22.0	
	2	19.3	24.8	
	3	14.6	23.0	
	4	15.0	22.0	
	5	9.1	19.3	
	6	12.0	20.9	
	7	10.9	22.9	
	8	13.4	22.8	
		$\overline{X}$ = 13.7	$\overline{X}$ = 22.2	8.5
June 26, 1972	1	16.4	----[5]	
	2	17.5	----	
	3	17.5	----	
	4	17.3	----	
	5	15.8	----	
	6	15.9	----	
	7	14.6	----	
	8	17.9	----	
		$\overline{X}$ = 16.6		
July 14, 1972	1	13.5	16.3	
	2	13.7	16.0	
	3	17.9	20.6	
	4	15.8	19.7	
	5	16.6	19.5	
	6	16.7	19.9	
	7	15.6	----	
	8	16.0	----	
		$\overline{X}$ = 14.4	$\overline{X}$ = 18.9	4.5

TABLE VII (continued)

Date	Sample Numbers	Moisture Percent Before[1,2]	After[3]	Moisture[4] Added
August 16, 1973	1	17.2	19.9	
	2	18.3	20.2	
	3	14.1	16.4	
	4	17.6	21.4	
	5	21.2	20.8	
	6	17.4	17.3	
	7	16.0	24.3	
	8	19.3	18.7	
		$\bar{X}$ = 17.6	$\bar{X}$ = 19.9	2.3

[1] All moisture calculations are on dry basis.

[2] Percent soil moisture before irrigation.

[3] Percent soil moisture after irrigation.

[4] Increase in soil moisture due to irrigation.

[5] No moisture data taken after irrigation due to rain.

which fell immediately following irrigation. Therefore, the irrigation efficiency could not be determined. On July 14, 1972 the irrigation application increased the soil moisture from 14.4 percent to 18.9 percent, or a difference of 4.5 percent. The application efficiency was 56.7 percent. The application efficiency was increased from the previous year by running the pump for short periods and allowing water to infiltrate between pumpings. On August 16, 1973 the irrigation application increased the soil moisture from 17.6 percent to 19.9 percent for a difference of 2.3 percent. This low increase in the moisture level was due to irrigation before the soil had dried out sufficiently to necessitate irrigation. As the rainfall exceeded normal throughout the season, this was the only period during which the soil dried enough to consider irrigation. As the corn was in the kernel formation stage, irrigation was performed due to the increased demand for water used by corn in this stage.

Corn Silage Yields

Corn was harvested from subplots within the test plot and also from check plots outside but near the irrigated plot. All harvesting was by hand cutting, and the green matter yield was determined in the field by weighing the corn from each subplot on the harvest site. Harvest data and conversions of those data to equivalent green-matter tonnage per acre are shown in Table VIII.

The excessive amount of rainfall which was near-or-above normal throughout the research period had much influence on the corn yields from the research plots. This rainfall most likely reduced the yields

TABLE VIII

Summary of Harvest Data from Cherokee Dairy Farm Test Plots

Date	Sub-plot	Actual wt. from subplots	Equivalent tonnage per acre of silage[1]
	Irrigated		
August 25, 1971	1	331.5	22.8
	2	295.9	21.2
	3	307.6	20.3
	Non-irrigated		$\overline{X}$ = 21.4
	1	240.0	16.5
	2	297.0	20.4
	3	246.7	17.0
			$\overline{X}$ = 17.9
	Irrigated		
September 5, 1972	1	269.9	18.6
	2	225.2	15.5
	3	299.6	20.6
	4	207.9	14.3
	Non-irrigated		$\overline{X}$ = 17.3
	1	264.8	18.2
	2	251.7	17.3
	3	253.1	17.4
	4	223.7	15.38
			$\overline{X}$ = 17.1
	Irrigated		
August 26, 1973	1	273	18.9
	2	238	16.4
	3	255	17.5
	Non-irrigated		$\overline{X}$ = 17.6
	1	190	13.1
	2	194	13.3
	3	175	12.1
			$\overline{X}$ = 12.8

[1]Green corn.

which could have been expected due to irrigation (Table IX).

An analysis of variance was applied to each year's data to determine whether or not the differences in corn silage yields on the sub-plots within the irrigated area and corn silage yields of check plots outside the irrigated area were statistically significant. The analyses of variance for each of the three years data collected are given in Table X.

TABLE IX

Precipitation in Inches for West Tennessee Experiment Station

Month	Long term mean	1971	Dev.[1]	1972	Dev.[1]	1973	Dev.[1]
May	3.97	4.38	+0.41	4.88	+0.91	6.21	+2.24
June	4.08	5.41	+1.33	3.44	-0.64	3.42	-0.66
July	4.46	5.94	+1.48	6.01	+1.55	2.78	-1.68
August	3.28	2.32	-0.96	3.19	-0.09	1.94	-1.34

[1] Deviation from long term mean.

TABLE X

Analyses of Variance Tables for Cherokee Dairy Farm Harvest Data

Source of variation	Degrees of freedom	Sum of Squares	Mean Squares	F
		August 25, 1971		
Treatment	1	18.03	18.03	5.91[1]
Pooled	4	12.21	3.05	
Total	5	30.24		
		September 5, 1972		
Replications	2	8.70	4.35	2.36[2]
Pooled	3	5.53	1.84	
Total	5	14.23		
		August 26, 1973		
Treatments	1	34.08	34.08	56.80[3]
Pooled	4	3.96	0.99	
Total	5	38.04		

[1] Significant at the 0.10 level of probability.

[2] Significant at the 0.25 level of probability.

[3] Significant at the 0.01 level of probability.

CHAPTER V

RESULTS AND DISCUSSION

In order to fully evaluate the benefits of an irrigation system, the irrigation system should be operated under conditions which will give an accurate and dependable evaluation of it worth. The conditions which are necessary to evaluate an irrigation system are conditions of severe drought. Under such conditions, an accurate determination of the value of an irrigation system can be conducted.

As the rainfall was near-or-above normal for the three-year period in which this research was conducted (no irrigation was performed during the 1972 crop growing season) the full value of the irrigation system used could not be fully determined. However, the value of the irrigation system for short dry periods between rainfall events was evaluated to a much higher degree as this was the type of situation encountered throughout the research period.

I. SOIL MOISTURE

The graded furrow method of irrigation is adaptable to many areas where the topography of the surface will permit land grading at a reasonable cost without permanent reduction in soil productivity. The uniformity of distribution and water use efficiency depend on the smoothness and uniformity of the land surface. Since the surface of a field is seldom of uniform slope and smoothness, land grading is a normal prerequisite to successful water application by the furrow irrigation method. The field on which the West Tennessee test plots for this research were located was improved by land graded in 1962 (29), and the slope and smoothness have been periodically maintained by use of a land plane since that date.

The overall application efficiency for the West Tennessee plots was 69 percent on plot one and 87 percent on plot two.

This is an indication that the soil type of plot one did not retain as much of the water applied by irrigation as did the soil type of plot two. This is only one situation in which the soil type has a bearing on the irrigation technique and resultant crop yields. The Collins soil on plot two has a higher available water holding capacity than does the Waverly soil on plot two. The statistical analysis points out the fact that there is a difference due to soil type (Table VI, page 49).

The soil moisture data from the Cherokee Dairy Farm where dairy manure slurry was applied by furrows can be seen in Table VII, page 50. All moisture measurements were made using gravimetric methods. The moisture added to the soil was determined by taking the difference between soil moisture values before irrigation and soil moisture values taken after irrigation (Appendix C). The overall average of moisture added to the soil in three irrigations during three years of tests was 5.10 percent. This was not as great an increase in moisture due to irrigation as was the increase in moisture due to irrigation at the West Tennessee Experiment Station. The most probable reason for the difference in moisture retention was the difference in the furrow grade at each location. At the West Tennessee Experiment Station, the average slope of the furrow was 0.36 percent whereas the average slope was 1.31 percent at the Cherokee Dairy Farm plots. This difference in slope resulted in increased velocity of water flow in the steeper furrows causing reduced infiltration with a corresponding reduction in application efficiency.

II. CORN SILAGE YIELDS

One of the best methods for determining the value of an irrigation system is to determine the increase in the yield and value of the crop irrigated as compared with the cost of irrigating the crop. The difference between the increased value of the crop and the costs of irrigation is the value of irrigation.

At the West Tennessee Experiment Station, the corn silage yield was determined by weighing the amount of silage harvested by a silage chopped from the irrigated plots and comparing this value with the yield of corn silage from check plots near the irrigated plots. The difference in corn silage yields between the irrigated plots and non-irrigated plots gave an indication of the value of irrigation from increased yields.

The harvest procedure was the same on both irrigated and non-irrigated plots. Therefore, the difference in yield between the two plots was attributed almost wholly to irrigation. Harvest data from the West Tennessee Experiment Station can be seen in Table V, page 47. In 1970, the increase in yield due to irrigation was 2.1 tons per acre on test plot one and 1.2 tons per acre on test plot two. This is an increase of 17 percent and 11 percent, respectively. In 1971, the increase in yield attributed to irrigation was 0.4 tons per acre on test plot one; however a decrease of 1.0 tons per acre occurred on test plot two. This was an increase of 3 percent on test plot one and a decrease of 6 percent on test plot two. The increase on test plot one represented an expected increase due to irrigation. The decrease in yield from test plot two of 6 percent may have been due to irrigation. This decrease in yield could have been due to factors present other than the water supply.

The rainfall exceeded the normal in 1971 which could explain the small increase in yield on plot one. This fact could also have had a bearing on the decrease in yield of plot two. Water was definitely not a limiting factor in the growth of corn during this growing season. The reasons for the decrease could have been due to a better stand of corn on the non-irrigated plot as compared with the stand of corn on the irrigated plot. Also, the 1971 irrigation application immediately preceeded significant rainfall, and this could have resulted in excessive moisture levels and reduced yields.

In 1972, the rainfall was such that irrigation was not required throughout the entire growing season. In 1973, irrigation was performed on test plot one only, and an increase in yield of 13 percent was attributed to irrigation. The reason for the overall decrease in yield for the 1973 growing season as compared with those of 1970 and 1971, was that of extensive and prolonged spring flooding which caused a very late planting date with resulting poor stands of corn and decreased yield. For this reason, test plot two was not irrigated in 1973. The stand of corn from the first planting was so poor that the first plot was replanted which resulted in an even later planting date than that of plot one. The second planting still gave a very poor stand of corn which resulted in the decision not to irrigate this plot. Comparisons would not have been valid, and the irrigation of plot one occurred late in the growing season which also tended to minimize the need for irrigation of plot two.

At the Cherokee Dairy Farm, corn silage was harvested by hand cutting and weighing in the field (Table VIII, page 53). This method of harvesting tends to show an increased yield on a given area when compared with machine harvesting. This is primarly due to the almost non-existent loss in green-matter weight when harvesting by hand. Machine harvesting is much faster, and more representative of field conditions, but losses occur in chopping and transfer of material from the chopper to the wagon.

In 1971 the average yield from the manure slurry irrigated plots on the Cherokee Dairy Farm was 21.4 tons per acre as compared to 17.9 tons per acre on the non-irrigated plots. This was an increase of 3.5 tons per acre or 20 percent. In 1972, the increase attributed to irrigation was 2 percent (0.2 tons per acre) and in 1973 the increase was 38 percent (4.8 tons per acre).

A substantial increase in corn silage yield resulted from irrigation with manure slurry over the three year period in which this research was conducted. The average increase in yield was 20 percent per year. Some of the increase in yield from this test plot can be attributed to nutrients the plants received from the manure in the slurry used to irrigate the plot. A separation of effects due to water and due to manure was not made in this study, but it could be included in future research in this area. The statistical analyses shown in Table X, page 56, show that irrigation was definitely a significant factor in increasing the corn yield from the test plots.

III. ESTIMATED COSTS

Although irrigation can offer for some crops and conditions, a great potential for increasing farm income, determining the costs associated with an irrigation system and the returns which may be expected is necessary.

Irrigation costs can be divided into three categories: fixed costs, variable costs, and additional production costs associated with higher yields. The fixed costs include depreciation, interest on the investment, taxes, and insurance. Variable costs include fuel, lubrication, labor and repairs (3).

Several factors which will vary from area to area and from farm to farm may be soil types, water sources, distance water is pumped, crops grown, and topography which make cost estimating difficult except for specific farms and specific situations. Therefore, the cost of irrigation will be limited in this discussion to that for the test plots only.

Initial investment costs for the West Tennessee Experiment Station are given in Table XI. Operating cost are shown in Table XII.

Irrigation costs at the Cherokee Dairy Farm test site were more difficult to determine since the pump and many facilities were part of a large unit purchased for another purpose. Due to existing pump facilities and irrigation pipe on the farm, the only equipment purchase necessary was six, 20-foot sections of 4-inch aluminum gated pipe with six gates per section. The cost for this pipe was $29.00 per section for a total cost of $174.00.

IV. EQUIPMENT AND PROCEDURE

The equipment used in this research was in excellent condition as most of the equipment was relatively new. The only problem encountered with the equipment was engine overheating on the first day the pump was used. This was most likely due to the tightness of bearings, rings, etc. in the new motor, and the problem was never encountered again after the engine had run for two to three hours.

Priming the pump for the 1973 season was difficult. This was most likely due to a combination of factors. The water level in the river which supplied the water for irrigation was low which increased the height of lift from the water level to the pump. The pump also had been started frequently while not in use to maintain the charge in the battery which started the pump. This resulted in drying of the grease in the main seal between the engine and the pump. When the seal is

TABLE XI

Initial Investment Costs For the West Tennessee Experiment Station Irrigation Equipment

Item	Costs
4-inch X 4-inch Gorman-Rupp pump and 4 cylinder jeep engine mounted on steel runners	$2,500
6-inch diameter X 20 feet long aluminum pipe with 6 variflow gates per section @ $54.55, three required	$ 163
6-inch elbow 90°	$ 20
6-inch end plug	$ 7
Bands and hooks @ $2.80, 15 required	$ 42
6-inch gaskets, @ $1.28, 25 required	$ 32
6-inch dresser couplings for suction line @ $12.00	$ 48
6-inch end screen for intake line	$ 11
10-foot section of 6-inch aluminum pipe @ $21.00, three required	$ 63
6-inch adapter, OD pipe to 4-inch NPT	$ 20
20-foot X 6 inches rubber hose (output side of pump to aluminum pipe)	$ 95
Assorted steel pipe and junk wheels for mounting pump on tandem axle frame	$ 40
TOTAL EQUIPMENT COSTS	$3,041

TABLE XII

Operating Costs

Item	Cost
Gasoline[1], oil, grease, etc. for one hour of operation (pump uses approx. 4.2 gallons per hour)	$1.84
Labor, per hour	$2.50
Repairs: No parts were purchased, but the pump was disassembled one time and the inner seal was packed with grease. The only repair cost was labor time to complete the job which took 2.5 hours	$6.25
Average operating cost to apply one acre inch of water during the test period	$4.54

[1] Gasoline prices calculated at $0.35 per gallon.

dry, air can pass by the seal which results in a loss of vacuum when attempting to prime the pump. The seal was re-packed with grease when this problem occurred and the pump was then primed with little difficulty. These difficulties were minor and required a short time to correct. However, when irrigation is necessary, time spent in making repairs results in decreases in crop yields. It is for this reason that all equipment should be maintained in good condition to prevent loss of irrigation time when it is badly needed.

CHAPTER VI

CONCLUSIONS

I. DROUGHT

Drought occurrence in Tennessee is unlikely but not rare. Tennessee rainfall records indicate that once or twice during every ten years, dry weather can be expected. It is this unexpected dry weather for which an irrigation system is intended. No reliable means are available of predicting which years will be adequate in rainfall and which years will not; therefore, uncertainty regarding rainfall is a valid reason for preparations against drought.

II. SOILS

Although more than one type of soil comprised some of the test plots, statistical analyses indicated that soil type on the research plots was not a significant factor in corn silage yield. This was most likely due to the similarity of the soil types involved. Although they were different types, they belonged to the same soil association series. Given a test area with two completely different soil types, a definite difference in yield should be expected when comparing the effects of the two soils.

III. YIELDS

The results from this research indicate that corn silage yields can definitely be increased by irrigation. This increase can be expected even during years of near normal rainfall. On the West Tennessee plots the mean increase in yield attributed to irrigation for three irrigations over a three year period was 1.2 tons per acre of corn silage. On the Cherokee Dairy Farm plots the mean increase in yield attributed to irrigation for three irrigations over a three year period was 2.8 tons per acre of corn silage.

Although total amounts of rainfall during the growing season are adequate, short dry periods may occur which can reduce yields slightly without irrigation. The value of irrigation has been proved in this research for this type of situation. However, the occurrence of heavy rainfall immediately after irrigation could result in decreased crop yield.

Irrigation with dairy manure slurry also produced marked increases in corn silage yield; however, the effects of the fertilizer value of the manure were not separated from those due to moisture alone.

IV. COSTS

The costs of an irrigation system cannot be fully evaluated unless a growing season of insufficient rainfall is experienced. However, brief periods between rainfalls where dry conditions exist can be used to evaluate the merits of an irrigation system. Even during periods of adequate rainfall, irrigation could in some years boost farm profits more than enough to offset the costs of irrigation. Major financial limitations associated with the type of irrigation described in this thesis are relatively high investment costs, labor required, and interest on the investment. The cost of an irrigation system can be likened to an insurance policy on crop success.

V. RECOMMENDATIONS FOR FURTHER STUDY

Since the rainfall was above normal for the past three growing seasons in which this experimental research was conducted (Table IX), little or no opportunity was available to determine the effects of irrigation on corn silage yields. Drought conditions were never reached at any time during the research.

In order to realize fully the advantages and benefits of supplemental irrigation, a crop growing season with very little natural rainfall is desired. This would create a drought situation which can normally be expected to occur once or twice every ten years in Tennessee. Only under drought conditions can the value of an irrigation system be determined.

One of the first recommendations for further study would be to conduct similar research during a year of limited rainfall so as to determine the value of irrigation under drought conditions. Another recommendation would be to increase the number of test plots in order to determine effects of different soil conditions on moisture deficiencies.

A recommendation to improve the dairy manure slurry research would be to design an experiment in which the fertilizer effects of the manure could be separated from the effects of the water.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Barker, J. C., and J. I. Sewell. "Effects of Spreading Manure on Groundwater and Surface Runoff". ASAE Paper No. 72-203. 1972.

2. Berberoglu, Hayri. "Evaluation of Irrigation Systems in Tennessee". Unpublished Masters Thesis. The University of Tennessee. Knoxville, 1957.

3. Brown, Edward R. Jr. "Plan Irrigation Cost Program to Fit your Farm Situation". Southeast Farm Weekly. July 1970.

4. Clark, Colin. The Economics of Irrigation. Oxford. Pergamon Press. 1970.

5. Cross, O. E. and P. E. Fischbach. "Water Intake Rates on Silt Loam Soil with Various Manure Applications". ASAE Paper No. 72-218, 1972.

6. Engineering and Watershed Planning Unit. Instructions and Criteria for Preparation of Irrigation Guides. Engineering Handbook section 15, Part 1 Far Western States and Territories, Soil Conservation Service, U.S.D.A. 1957.

7. Engineering Field Manual SCS, U.S.D.A. September 1969.

8. Farm Irrigation. North Carolina Agricultural Extension Service. Extension Circular No. 400, November 1956.

9. Holt, B. E. "Corn Yields and Evapotranspiration as Influenced by Moisture Level, Nitrogen Level, and Several Climatic Factors." Unpublished Masters Thesis, The University of Tennessee, Knoxville, 1964.

10. Houk, Ivan E. Irrigation Engineering. Volume II, New York, John Wiley and Sons, Inc. 1956.

11. Huffman, R. E. Irrigation Development and Public Water Policy. New York. The Ranald Press Co. 1953.

12. Hydraulics of Surface Irrigation. Agricultural Research Service U.S.D.A. October 1960.

13. Investment and Operating Costs of Irrigation. Mississippi State University Agricultural Experiment Station Bulletin No. 599. 1958.

14. Irrigation. University of Arizona Extension Service Bulletin A-20. 1970.

15. Irrigation. SCS National Engineering Handboodk, USDA. 1967.

16. Israelson, Orson W. and V. E. Hansen. Irrigation Principles and Practices. New York, John Wiley and Sons, Inc. 1962.

17. Lateef, N. A. "Irrigation Fundamentals." University of Tennessee Booklet.

18. Little, W. C. "The Design of Furrow Irrigation Systems." ASAW Paper. 1960.

19. National Irrigation Symposium Papers, ASAE. 1970.

20. Olivier, Henry. Irrigation and Climate. London, Edward Arnold (Publisher) Limited. 1961.

21. Olivier, Henry. Irrigation and Water Resources Engineering. Great Britain. The Camelot Press LTD. 1972.

22. Parks, W. L. and H. B. Smith. "How Much Water Does it Take." Tennessee Farm and Home Science. 1962.

23. Renfo, G. M. "Irrigation by the Furrow Method in the Southeastern States". SCS Paper. September 1956.

24. Rubey, Harry. Supplemental Irrigation for Eastern United States. Illinois: The Interstate Printers and Publishers. 1954.

25. Ruttan, Vernon W. The Economic Demand for Irrigated Acreage. Maryland: The John Hopkins Press. 1965.

26. Sally, H. L. Irrigation Planning for Intensive Cultivation. New York: Asia Publishing House. 1968.

27. Schwab, G. O., R. K. Frevert, T. W. Edminister, and K. K. Barnes. Soil and Water Conservation Engineering. Second Edition. New York: John Wiley and Sons, Inc. 1966.

28. Sewell, J. I. 1973. Manure Slurry Irrigation System Receiving Lot Runoff. Transactions of the ASAE, 16:2. pp. 350, 351, 352, and 353.

29. Sewell, John I. and Ben P. Hazelwood. 1966. Drainage and Land Grading on a Bottom Land Field Area in West Tennessee. Agricultural Experiment Station. Bulletin 408.

30. Soil Survey Knox County Tennessee. U.S.D.A. Soil Conservation Service. 1966.

31. Soil Survey. Madison County Tennessee. U.S.D.A. Soil Conservation Service. 1962.

32. Sprinkler Irrigation. Sprinkler Irrigation ASsociation. Maryland: Editor's Press. 1969.

33. Sprinkler Irrigation Handbook. Rain Bird Sprinkler Manufacturing Corp. 1970.

34. Swanson, N. P., C. L. Linderman, and J. R. Ellis. "Irrigation of Perennial Forage Crops with Feedlot Runoff". ASAE Paper No. 73-241. 1973.

35. van Bavel, C. H. M. and F. J. Verlinden. Agricultural Drought in North Carolina. North Carolina Agricultural Experiment Station. Technical Bulletin No. 122. June, 1956.

36. Zimmerland, Josef D. Irrigation. Volume II, New York: John Wiley and Sons, Inc., 1966.

APPENDIXES

APPENDIX A

TABLE XIII

Summary of Neutron Soil Moisture Data at West Tennessee Experiment Station Irrigation Plots

I. Before Irrigation - July 13, 1971

Subplot & Depth	Scaler Reading Location 1	Conversion to lbs. water/ft^3	Scaler Reading Location 2	Conversion to lbs. water/ft^3
A 6"	17014	10.2	22758	13.8
12"	27049	16.2	27623	16.4
18"	34614	21.0	33821	20.4
B 6"	21948	13.1	29740	17.9
12"	32351	19.3	31294	18.8
18"	35544	21.1	34432	20.6
C 6"	20161	12.1	21653	12.8
12"	28896	17.1	26566	16.0
18"	30862	18.4	33426	20.0
D 6"	13873	8.4	9591	5.6
12"	21450	12.8	24451	14.8
18"	23641	14.0	26544	16.0
E 6"	9101	5.6	24032	14.4
12"	19803	11.8	29642	17.8
18"	20464	12.2	31623	19.0
F 6"	7033	4.3	19923	11.8
12"	17544	10.6	28392	17.2
18"	25221	15.0	31727	19.0

TABLE XIII (continued)

II. After Irrigation - July 14, 1973

Subplot & Depth	Scaler Reading Location 1	Conversion to lbs. water/ft^3	Scaler Reading Location 2	Conversion to lbs. water/ft^3
A 6"	33955	20.4	38560	23.0
12"	39117	23.4	36595	21.8
18"	40245	24.0	39350	23.6
B 6"	34284	20.4	43054	25.8
12"	41541	24.8	41382	24.8
18"	41022	24.6	41183	24.7
C 6"	32751	19.6	39732	23.8
12"	41750	25.0	38031	22.8
18"	41200	24.6	39082	23.2
D 6"	26972	16.1	31586	18.0
12"	28346	17.0	33640	20.1
18"	27160	16.2	31767	19.0
E 6"	24545	14.6	29787	17.8
12"	33542	20.1	35746	21.3
18"	30943	18.3	37063	22.0
F 6"	27614	16.5	27130	16.4
12"	36647	22.0	33678	20.2
18"	30948	18.3	37075	22.1

APPENDIX B

TABLE XIV

Summaries of Discharge Rates from Gated Pipe

Time of pumping in minutes	Flow from gate in gallons/minute	Total output from 18 gates in gallons
I. West Tennessee Experiment Station, July 13, 1971		
7	12	1,512
76	15	20,520
26	30	14,040
67	30	36,180
126	10	22,680
Total Application - 94,932 Gallons		
II. Cherokee Dairy Farm, July 9, 1971		
13	20	3,120
16	20	3,840
5	20	1,200
44	16	8,448
Total Application - 16,608 Gallons		

APPENDIX C

TABLE XV

Moisture Tension Determinations
For Etowah Soil

Horizon	Tension Bars	Average Moisture percent by volume
A	1/3	34.14
	2	23.68
	5	19.77
	15	16.95
B	1/3	38.69
	2	22.91
	5	19.44
	15	17.16

VITA

James Baxter Wills was born in Mountain City, Tennessee, on July 16, 1948. He attended Laurel Bloomery Elementary School and was graduated from Johnson County High School in 1966. The following September he entered the University of Tennessee; and in June, 1970, he received a Bachelor of Science degree in Agriculture with a major in Agricultural Mechanization. Immediately following graduation he accepted a research assistantship at the University of Tennessee Graduate School and began study toward the Master of Science degree in Agricultural Mechanization. On December 19, 1970 he was married to Charlotte Ann Walters of Knoxville, Tennessee. They have no children.