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HIGHLIGHTS OF IRRIGATION RESEARCH

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Irrigation is generally considered to be the artificial application of water to land for the purpose of supplying the moisture essential for plant growth. While its object is agricultural, on account of the nature of the works required for the control of water it includes a special branch of engineering, which involves a knowledge of the available water supply, its conservation and application to the land, the characteristics and needs of different soils, and the requirements of the particular crops to be produced.

Irrigation, probably one of the oldest occupations of civilized man, antedates recorded history. Asia, Africa, Europe, and America have remains of irrigation works of unknown age, and hieroglyphic records of the Pharaohs give evidence of its practice in Egypt as early as 2500 B.C.

Extensive and well-built irrigation systems existed in America as far back as the time of the Spanish conquests. Traces of such works have been found in southern Arizona, New Mexico, Colorado, and California. Modern irrigation in this country began about the middle of the 18th century with the watering of the gardens in the hills and deserts of California by the missionaries from Mexico. The use of irrigation throughout the United States, especially in the arid regions, has shown a fairly steady increase since the turn of the century.

Census reports began including the number of acres under irrigation in the state of Indiana only as late as 1940, and since that time the total acreage has risen from 685 acres to 5,339 in 1950 and 17,237 in 1959. National figures for the corresponding period of time show a similar increase in irrigated acreage.

Several factors have contributed to this more extensive use of supplemental water. One of the most important of these has been the national government's participation in the constructions of large dams, reservoirs, and irrigation projects. The majority of these were developed in the West and Southwest, but their influence has been felt in all sections of the country.

In Indiana the largest increases were in counties having rather droughty soils, such as Jasper, Marshall, Pulaski, St. Joseph, Vigo, and Starke. Influential factors here include the current high costs of production which make it necessary to reduce the risks of droughts and other hazards whenever possible.

One indication of the impact of irrigation upon the agricultural economy is the fact that the 7.2 million acres of irrigated land brought into production between 1949 and 1959 is roughly equivalent in productive capacity to the 25 to 30 million acres taken out of agricultural production during the same period for nonfarm use and by the acreage allotment and soil bank programs.1/

The development of light-weight, portable sprinkler equipment now makes it possible to irrigate any type of field or crop that is within reach of a water supply. Important also, are biological innovations in the field of plant science that have resulted in higher yielding varieties and a better understanding of soil fertility, and pest and disease control. As potential crop yields have been pushed upward soil moisture from natural sources has become more important as a limiting factor.

The use of irrigation has many applications in modern day agriculture. Vittum, Peck, and Carruth (1)2/ conducted irrigation research to determine the effects of supplemental water upon sweet corn production. They concluded that irrigation significantly increased the number of marketable ears per plant in two out of four years in which irrigation was applied. Results showed that 1.09 ears were harvested from each plant on nonirrigated plants as compared to 1.19 ears from each plant on irrigated plots. This increase was highly significant.

1/ V. W. Ruttan, "Our Growing Farm Output Potential", Economic and Marketing Information for Indiana Farmers, Purdue University, Lafayette, Indiana, Jan. 29, 1960 pp. 2-4.

2/ Numbers in parentheses refer to the bibliography at the end of the paper.

Templeton and others (2) report that one of the most noticeable effects of irrigation on pastures was the increase in amount and growth of white clover. Superior performance on irrigated pastures during the second month of grazing is believed to be associated with the higher clover content.

Dr. Peterson and Dr. Hagen reported that studies at the University of California on the effect of moisture stresses on the growth of Ladino clover showed that frequent irrigation produced more fresh weight but little more dry matter than did plots that received less frequent irrigations but had some available moisture in the soil at all times. They concluded that the most economical point to irrigate is when 75 percent of the available moisture in the effective root zone has been depleted.

Pogrell and Kidder (3) report that methods of frost control by irrigation have been used successfully since 1949. They found that the effectiveness of maintaining frost protection is influenced by the precipitation rate and the frequency of application. An increase in protection was obtained with higher precipitation rates and holding the application intervals constant.

Irrigation has also been used by farmers to establish seedings in wide-spaced corn rows, and to establish and maintain a double cropping system such as planting and harvesting a crop of soybeans after wheat. Irrigation in these instances provides adequate moisture at the time of germination.

Agronomists such as Russel and co-workers (4) have studied corn and soil moisture relationships and have determined that moisture absorption takes place directly beneath the plant, then laterally, and into greater depths.

Agronomists Howe and Rhoades (5) conducted irrigation experiments to determine the effect upon corn yields by irrigating during different growth stages. They isolated the plant's critical period for water as that period when tassels and silks were forming. Robins and Domingo (6) observed that moisture deficits lasting only one or two days during tasseling or pollination periods reduced corn yields as much as 22 percent. When the duration of drought was six to eight days yields were reduced about 50 percent.

Kiesselback (7) reported that severe early drought stunted plants, delayed their silking, and caused many plants to be partially or completely barren. Drought after pollination also shortened ears and reduced the kernel size.

Husky and later Paddick divided the development of the corn plant into five distinct stages. These stages are (1) early vegetative growth from planting to flower differentiation; (2) rapid vegetative growth from a plant height of about 50 centimeters to silking; (3) pollination and fertilization; (4) grain production from fertilization to maximum dry weight of the grain; and (5) maturation or drying of grain and stalk.

Shubeck and Caldwell (8) conducted an experiment to investigate the effects of various fertilizer treatments and plant populations on corn and to measure the effect of stand densities on the moisture content of the soil. They found that:

1. Increased population increased yield up to a point.
2. Increases in population were associated with an increase in poor ears and a reduction in the ear weight.
3. Differences in stand caused little difference in height of corn, but silking dates were delayed as much as five days by having 17,780 stalks per acre instead of 3,556. Small differences in maturity were found.
4. There seemed to be a correlation between moisture supply in August and the response of corn to sidedressed nitrogen.
5. Sidedressed nitrogen resulted in increases in the nitrogen content of grain, regardless of yield response.
6. An increase in plant population caused a decrease in the nitrogen content of grain.

Paschal, and French (11) found that in 13 experiments completed at Ontario, Oregon, the increase in crude protein was roughly 200 pounds per acre. This increase was sufficient to pay the entire cost of the nitrogen. The increase in protein on four other experiments were valued at $7.50 above the cost of nitrogen.

Boswell and others (10) conducted experiments in Georgia to determine the effect of irrigation, nitrogen, and plant population on corn production. In every instance irrigation increased corn yields. The effect of irrigation was clearly illustrated by significantly higher yields and by comparing the response to nitrogen, with and without irrigation, as plant population increased. With irrigation, yields increased at all plant populations nitrogen was increased from 60 to 120 pounds per acre. However, without irrigation only the lowest plant populations showed an increase from added nitrogen. Extreme yields from irrigated and nonirrigated plots were 62.6 and 119.6 bushels per acre, respectively.

This is one of the first publications mentioning the interaction between water and nitrogen, although it is doubtful that the researchers were fully aware of the significance of these results. In this study irrigation was applied when approximately 25 percent of the corn plants wilted by midday. Wilting is not considered to be a good indication of soil moisture nor of plant needs. Wilting will occur any time vaporation is greater than transpiration, whatever the cause. A hot dry wind can cause temporary wilting regardless of the moisture content of the soil. This study is typical of many other studies of irrigation vs. nonirrigation in which irrigation was used as a substitute for normal rainfall.

Presently there is general agreement among agronomists, animal husbandrymen, and economists that irrigation can and should be done scientifically. Differences of opinion occur within and among these groups in regard to the methods of analyses and the measurements of the water input. Some of the most common methods of expressing relationships are cross-tabulation, graphic analysis, and mathematical methods involving regression and correlation. The mathematical methods are the most widely accepted of the three procedures. The water input is generally measured in one of the following three ways: (1) Consumptive use, (2) A function of drought intensity, and (3) Total inches of water received.

Rhoades and associates (5) are of the belief that the amount of water needed at each irrigation is determined by the rate of use, usually called consumptive use, and the number of days between irrigations. Taking this view, the soil is looked upon as a large storage reservoir which must be replaced from time to time in amounts equal to that used by the plant. Agronomists in particular have been very interested in consumptive use and have, as a result, a vast number of tables showing consumptive use calculations for all important crops.

When applying the consumptive use concept the producer must then carefully consider three important points: (1) How much water the soil has in each of its layers, (2) How fast the crop is using moisture from the soil (transpiration) and how much is evaporating from the soil surface, and (3) How much of the total water held in the soil the plant can use or extract before a moisture stress occurs.

The producer need only irrigate when the available soil moisture is low enough that the plant is in danger of becoming under a moisture stress. Each irrigation application should be sufficient to completely fill the soil. This method can be used for any crop once the demand, supply, and rate of use has been determined. This is done independently of the effect of water upon plant growth, yield or quality. It is based on plant use and physical characteristics of the plant and soil. This method of determining when and how much water to apply through irrigation is quite widely used by irrigation engineers, agronomists, and farmers.

This method relies upon the assumption that between the moisture levels of field capacity and plant wilting, water is equally available to the plant and that moisture stress occurs at wilting. The assumption is made even though water at the upper limit, field capacity, is withheld from the plant roots by a tensional force of about only 1.5 pounds per square inch, whereas water at the lower limit, permanent wilting percentage, is withheld by a tensional force of about 200 pounds per square inch. However, it is pointed out that the relationship between soil moisture tension and moisture content is such that there is little change in moisture tension until the permanent wilting point is approached.

Other researchers such as Van Bovel (11) and Verlinden (12) believe that the level of drought can be measured, or indexed, according to the number of drought days that occur during the growth period under study. Using the drought criteria as a measure of irrigation effectiveness it is possible to describe the yield effects of irrigation under varying drought conditions. Other inputs such as different fertilizers and seeding rates can be included in the analysis.

The essential method of analysis when using the level of drought concept is to consider irrigation as a means of reducing the intensity of drought. The amounts of water applied by irrigation are not considered as such, but only as this water overcomes a drought condition. The drought level or intensity occurring during the crop growing season is measured under all irrigation treatments, including the zero level of application, to arrive at a quantitative value of the effect of irrigation in the reduction of drought. The biggest problem in this method is determining what level constitutes a drought day.

Knetch (13, 14) in studying fertility used secondary data to assign weights to the individual drought days occurring during a three year experiment in accordance with the time of occurrence during the growing season. The resulting index values were considered with different nitrogen treatments to derive an estimate of the relationships between corn yield, nitrogen, and drought level. The optimum level of nitrogen was then shown as a function of the drought conditions experienced. This made it possible to determine the most profitable rate of nitrogen application for any level of drought expected in a given area.

A further extension of this method is through the use of rainfall data to reconstruct a probability distribution of each drought intensity. Once the probability of occurrence of each drought intensity is known, maximum profits over a longer period of time can then be determined. Furthermore, once these probabilities of expected returns are given, an individual would be in a position to choose the production method in line with his own personal objectives.

Ehlers (15) using the concepts of drought measurement and the probabilities of drought occurrence developed by Van Bavel studied the effect of droughts during three time periods on the production of corn. The growing season was divided into four successive periods. Periods A and B preceded tasseling and were 33 and 32 days in length, respectively. Period C included 14 days at tasseling and period D was the 31 day maturing period after tasseling. A relationship between the number of drought days in each of these periods and corn yield was determined by multiple correlation analysis. Period A was found to be not significant and was omitted. The expression accounted for 50 percent of the variability in corn yields.

Using a simplified historic relationship, it was found that the average yield reduction is approximately five bushels for each one-inch deficiency in available water. The author indicates that the production function so developed would be useful in making forecasts of crop production.

In contrast to the attempt to interpret moisture stress from measurements of available soil moisture U.S.D.A. scientist L.M. Namken, Weslaco, Texas, measured moisture stress by comparing the water balance of the plant with the maximum water it is capable of taking up. This method is based on the fact that plants needing water are in a condition known as plant moisture stress. The ratio between the weight of a sample of plant tissue under field conditions and its weight after it has become fully turgid is the index of moisture stress of the plant.

Niehause (16) studied irrigated corn production on Fox sandy loam in southern Indiana. In this study every effort was made to calculate a "water use" concept similar to the consumptive use concept applied by Rhoades and others. Soil moisture was maintained at three levels: between wilting and 100 percent of field capacity, between 40 percent and 100 percent of field capacity and between 75 percent and 100 percent of field capacity. Each time the soil moisture became lower than the limits set irrigation was applied to bring the soil mosture up to field capacity. Water applied was further adjusted for evaporation which occurred during irrigation. The adjusted inches applied were then used as an estimate of "water use". Several mathematical models were fitted to the recorded data. An R^2 of .3936 was the highest multiple coefficient of determination obtained. The unexplained variation challenges the methods and general procedures used. Difficulty in the measurement of the "water use" variable may have given rise to errors in the data used in regression.

The data used by Niehaus was later rerun using the same mathematical functions, but measuring the water variable as total inches of water received (rainfall plus irrigation). A considerably larger R^2 of .82 was obtained. Difficulty in the measurement of the "water use" variable may have given rise to errors in the data used in regression.

Smith (17) studied the effect of water, nitrogen, and seeding rate upon corn yield. The predicted total product curve for water was near linear in form and gave rise to marginal physical products as great as 16.26 bushels per acre inch. The relationship between water and corn yield was complex and influenced by both nitrogen and seeding rate. Interaction between nitrogen and seeding rate did not exist. Thus, the physical yield response to nitrogen and seeding rate were independent. The absolute level of neither the nitrogen or seeding rate total product curve was affected by the level of the other.

Hartman (18) studied the effect of water and seeding rate on corn production in southwestern Indiana. On the basis of quadratic and square-root quadratic production functions the long and short-run economic feasibility of irrigated corn production was determined for that area and soil type. He concluded that even during the ten consecutive wettest years net returns were higher and less variable for irrigated corn production than for non-irrigated. Water was measured as the number of inches received during the growing season (rainfall plus irrigation).

Many of the problems confronting irrigation research today are methodological. How can we best measure the water input so that more accurate and consistent input-output relationships can be obtained? How can the total relationships among several important variables which simultaneously determine crop yields be determined? How can factors such as natural soil characteristics (fertility, drainage, structure, and tilth) be quantified so that production estimates can be made, for example, across soil types. The answers to these questions should, perhaps, be the main pursuits of future irrigation research.

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