CONSUMPTIVE USE OF WATER BY PLANTS AND NITRATE CONTENT IN SOIL AS INFLUENCED BY CROPPING SEQUENCE AND FERTILIZER TREATMENTS

A Thesis

Submitted to

The Faculty of Graduate Studies and Research

The University of Manitoba

In Partial Fulfillment

of the Requirements for the Degree of

Master of Science

by

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February 1959

ACKNOWLEDGEMENT

The writer wishes to express his indebtedness to Dr. R. A. Hedlin, Chairman of the Soils Department, The University of Manitoba, who suggested the project and under whose supervision the investigation was conducted.

Acknowledgement is also made to Sherrit Gordon Mines Limited and Harrisons and Crosfield (Canada) Limited for the Fellowship granted to The University of Manitoba which encouraged this project to be undertaken.

ABSTRACT

Investigations conducted at the University of Manitoba have shown that fertilizer and manure treatments in a cropping sequence increase yield of wheat and efficiency of water use, but have little effect on the consumptive use of water under the weather conditions which occurred in 1956 and 1957.

Sufficient moisture is stored in the fall and winter of a crop year to provide for the establishment of a succeeding crop. Sufficient rain falls during the growing season to insure a crop, but may not necessarily provide optimum conditions for crop growth.

On the plots which were fallow in 1956 and 1957, a loss of moisture occurred during the period May to August even though the precipitation for this same period was 8.17 inches and 10.18 inches, respectively.

Accumulation of nitrates occurred in summerfallow plots. Nitrate accumulation was greater on manured plots than on plots which had not received manure. There appeared to be an inverse relationship between fallow frequency and the accumulation of nitrates in the fallow year. Leaching of nitrates occurred on the fallow plots in the period August to October. High accumulation of nitrates was found below the root zone on plots which were sampled to a six foot depth.

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I. INTRODUCTION

Summerfallowing was introduced into Western Canada by Angus McKay of the Indian Head Experimental Farm in 1889. He believed that fallowing was the best method to insure a crop and that this could be attributed to the moisture conserved during the fallow year. Since 1889 the acreage summerfallowed has increased steadily until, even in relatively humid areas such as Manitoba, about 30 percent of the crop acreage lies fallow each year. It is probable that this large acreage lies fallow because farmers recognize that higher yields usually are obtained on fallowed land. Also, fallowing distributes work throughout the summer permitting more efficient use of labour and machinery.

The increase in yield on fallow lands has been attributed to release of plant nutrients, to storage of moisture and to weed control. Therefore, if the moisture is adequate and weeds are not a serious problem, it should be possible to maintain high yields on non-fallow fields by applying plant nutrients in the form of fertilizer and manure.

This study was undertaken to observe the effect of fertility and cropping sequence on the yield of wheat; to determine the consumptive use of water and to evaluate the efficiency of water use under various rotational sequences and varying levels of fertility; to evaluate the efficiency of summerfallow in its ability to store moisture; and to determine the amount and distribution of available nitrogen in the nitrate form present in the soil under different cultural practices.

To evaluate the efficiency of water use under the various rotational sequences and varying levels of fertility, the consumptive use of water and the yield of wheat per acre were used. The consumptive use of water in inches was converted to pounds of water consumed while the yield of wheat was converted to pounds of grain produced. By this method, it was possible to obtain the efficiency of water use in terms of the pounds of water consumed per pound of grain produced or evapotranspiration-grain ratio.

II. REVIEW OF LITERATURE

A. Consumptive Use of Water

Consumptive use of water or evapotranspiration refers to the total volume of water per unit of cropped land utilized in tissue growth and transpiration, plus that evaporated from the soil in either one year or one growth period. Consumptive use of water depends on such factors as climate, type of soil, fertility of soil and plant species.

1. Climate and Its Relation to Consumptive Use.

Climate determines what Thornthwaite (41) refers to as potential evapotranspiration which is defined as the transfer of water that would be possible under conditions of full vegetative cover and ideal moisture supply. Thornthwaite presented formulae by which potential evapotranspiration may be determined and showed that the average annual water need in the United States ranges from less than 18 inches in the mountains of the West to more than 60 inches in areas of Arizona and California. It is less than 21 inches along the Canadian border. Briggs and Shantz (24) showed that at different locations in the United States, the water requirement of the second crop of Grimm alfalfa ranged from 518 to 1005 grams of water per gram dry weight of alfalfa.

Penman (30) determined the evapotranspiration from small areas of closely clipped grass, fertilized and unfertilized, and found that the fertilized grass yielded more than twice as much as the unfertilized grass, but the evapotranspiration was the same. He suggested that as long as soils remain moist and well covered with growing vegetation, the evapotranspiration is controlled by environmental conditions and is independent of the nature and yield of vegetation.

Staple and Lehane (39), Brown (14), Cole and Mathews (6) have shown that in semi-arid regions, yield of dry matter is dependent on water use and that 5.0 to 7.4 inches of water were required before any wheat could be produced. Staple and Lehane (40) have shown that once there is sufficient moisture to produce a wheat crop, each additional inch of water increases the yield by 3.5 bushels per acre. When moisture used is above 10 inches, each additional inch of water increases wheat yield by about 6 bushels per acre. Cole and Mathews found that wheat yields were increased by 2.0 bushels per acre for each additional inch of water used.

2. Effects of Fertility on Consumptive Use.

Hanks and Tanner (18) compared the effects of irrigation levels and degree of fertility on efficient use of water by plants and found that, where water is not limiting, high fertility results in a more efficient use of water and is essential if the highest yield per unit of water applied is to be obtained. The effect of increased fertility level in increasing efficiency of water use has been confirmed for corn by Montgomery and Kiesselbach (24), for sudan grass by Weaver and Pearson (45), and for wheat by Singh and Mehta (35) and Zubriski and Norum (47).

Vandecaveye (42) recently stated that in areas in Washington State which receive more than 14 inches of precipitation annually, available nitrogen and not soil moisture is the limiting factor in crop production. Results obtained during 31 years of annual cropping to wheat showed an average increase of 10 bushels of wheat per acre when nitrogen was applied either alone or as a supplement to the wheat straw residue of the previous crop.

3. Influence of Plant Factors on Consumptive Use.

The plant factors which influence the consumptive use are rooting depth and ramification, plant vigor and growth stage, and the ability of a plant to survive at low soil moisture content. Kelly (24) has shown that on any one kind of soil, most plants wilt or stop growing at about the same moisture content, but their drought resistance or ability to resume growth after wilting varies.

Bowen (7) and Housten (21) have shown that under an adequate moisture supply, 80 to 90 percent of the total water used was obtained from the upper 2 to 3 feet for crops such as wheat, barley and rye, while for alfalfa, 70 to 75 percent of the total water used was obtained in the upper 3 feet. Kmoch et al (25) indicate that relatively dry conditions induce plants to develop a more extensive root system than do moist soil conditions. A more efficient utilization of subsoil moisture occurred with application of nitrogen fertilizer which increased root weight at all moisture levels and nearly all soil depths.

The quantity of water that different crops will extract from the soil varies with the stage of growth and kind of plant. Although the root extraction pattern at maturity depends largely on the kind of plant, it can be modified by such variables as thickness of stand, soil aeration, soil fertility, dense soil layers and height of water table (23).

B. Storage of Moisture

Soils vary greatly in their ability to hold moisture. It has been shown by a number of workers (24, 38, 17, 46, 28), that texture is the main factor affecting water retention. Fine textured soils can retain a higher percentage of water than coarse textured soils. Jamison (22) and Feustel and Byers (4) showed that, except for sandy and medium textured soils, organic matter does not increase the capacity of a soil to store water. Aggregation and structure development in soil increase the volume of pores that store moisture.

Summerfallowing results in storage of appreciable quantities of water although the percentage of precipitation stored is small. Staple and Lehane (37) have shown that under conditions which prevail in Southern Saskatchewan, the moisture stored in soil during a summerfallow period is usually only 15 to 30 percent of the precipitation received. As much as 62 percent of the total stored moisture was conserved during the first fall and winter. The average moisture conserved in fields at seeding time was 2.2 inches in stubble land and 4.0 inches in fallow land. At North Platte, Nebraska, Zook and Weakly (6) found that on the average only 27 percent of the precipitation received during a 12.5 month period was present in the soil at the time the next crop was planted.

Staple and Lehane (37) state that showers must be greater than 0.4 to 0.8 inches or occur at frequent intervals in order to saturate the dry surface soil and cause water to move downward below the evaporation zone which they consider to be to a 4 to 5 inch depth from the surface. Hopkins (20) infers from derived equations that, under average conditions, a one day rain to the amount of 0.36 inches in May and June and 0.46 inches in July and August would be required to offset the subsequent evaporation during a ten day period. On the average, 66 percent of a one day rain of one inch in May or June would be conserved at the end of 10 days while only 30 percent would be retained if the same amount of rain was received in five daily showers of 0.20 inches.

C. Formation and Accumulation of Nitrates in the Soil

The formation of nitrates from organic matter involves two processes - mineralization and nitrification (44). Ammonia is formed from the organic matter in the mineralization process and nitrate is produced from ammonia and nitrate in the nitrification process. These processes are the result of micro-organic activities and hence are influenced by environmental conditions.

Russel et al (34) have shown that at 5°C. nitrate production is very slow. Above this temperature, the rate of nitrate production increases rapidly and reaches a maximum at 35°C. A further increase in temperature results in a decrease in nitrate production, no nitrates being produced at 55°C.

Not all workers agree as to optimum moisture content for nitrate production in soils. Calder (9) and Russel (34) indicate that nitrate production occurs between 15 percent moisture and waterlogging but that there is no optimum moisture content. Other workers, such as Fitts et al (15) and Gainey (9), indicate that the optimum moisture content is 22 to 30 percent depending on the texture of the soil. Greaves and Carter (9) showed that for a wide variety of soils, nitrate production reached a maximum value when the moisture content was at 50 to 60 percent of field capacity.

Gainey (16), Fitts et al (15), Allison (2) and Stanford et al (36) indicate that a relationship exists between the nitrogen content of soils and their ability to accumulate nitrates. Larson and Mitchell (27) have shown an increase in the rate of nitrification as a result of manuring. They found a higher nitrate content in a fallow field which had been manured than in one to which no manure had been applied. The application of two and one-half tons of straw slightly decreased nitrate accumulation during the summerfallow period. Albrecht (1) indicates that a straw mulch reduces the accumulation of nitrates of clay soils. He attributes this decrease to the higher moisture content of mulched soils and shows that as the moisture content decreased, nitrate accumulation increased. It is probable that in the field a higher moisture content tends to reduce soil temperature.

Krantz et al (26) found that nitrates accumulated at the surface after a prolonged dry period, but any moderate rain moved the nitrates downward into the main root zone. Russel and Richard (32) and Bate and Tisdale (3) state that a relationship exists between rainfall and the amount of nitrate in the drainage water of uncropped land. Doughty et al (11) showed that high concentration of nitrates were found to a depth of seven feet on summerfallow fields following early fall rains while on virgin soils no nitrates were found.

III. INVESTIGATIONAL PROCEDURE AND RESULTS

A. Field and Laboratory Methods

1. Plot Layout and Sampling Procedure

This study was conducted on the Fertility Field at The University of Manitoba on plots which were laid out in various cropping sequences in 1919 on soil types which are clay in texture and are members of the Red River and Fort Garry associations. These soils are described by Ehrlich et al (12). The experimental area included Ranges 26 and 27 and one plot in Range 28 in Block 2. Each range consists of eleven main plots, each of which is 1/40 acre in size. A field plan of the experiment is presented in Fig. 1.

In Plots 1 to 10 the cropping sequence is the same on Ranges 26 and 27 and is as follows:

Plots 1 and 2 - a fallow-wheat rotation

Plots 3, 4 and 5 - a fallow-wheat-wheat rotation

Plots 6, 7, 8 and 9 - a fallow-wheat-wheat-wheat rotation

Plot 10 - continuous wheat

The cropping sequence on the other plots sampled was:

Plot 11 - Range 26 - continuous corn

Range 27 - continuous oats

Range 28 - continuous barley

Rotation	Range 27 Year	Range 27 Crop	Plot No.	Range 26 Year	Range 26 Crop
Cont.	1957	Oats	11	1957	Corn
	1956	Oats		1956	Corn
Cont.	1957	Wheat	10	1957	Wheat
	1956	Wheat		1956	Wheat
Fallow	1957	1st.yr.wheat	9	1957	1st.yr. wheat
	1956	Fallow		1956	Fallow
Wheat	1957	Fallow	8	1957	Fallow
	1956	3rd.yr.wheat		1956	3rd.yr. wheat
Wheat	1957	3rd yr.wheat	7	1957	3rd yr. wheat
	1956	2nd yr.wheat		1956	2nd yr. wheat
Wheat	1957	2nd yr.wheat	6	1957	2nd yr.wheat
	1956	1st yr.wheat		1956	1st yr. wheat
Fallow	1957	1st yr.wheat	5	1957	1st yr. wheat
	1956	Fallow		1956	Fallow
Wheat	1957	Fallow	4	1957	Fallow
	1956	2nd yr.wheat		1956	2nd yr.wheat
Wheat	1957	2nd yr.wheat	3	1957	2nd yr.wheat
	1956	1st yr.wheat		1956	1st yr.wheat
Fallow	1957	1st yr.wheat	2	1957	1st yr.wheat
	1956	Fallow		1956	Fallow
Wheat	1957	Fallow	1	1957	Fallow
	1956	1st yr.wheat		1956	1st yr.wheat

NOTE: The four rotations presented are F-W; F-W-W; F-W-W-W; and continuous wheat.

NOTE: Plot 11, Range 28 was included in the experiment as a continuous barley treatment.

Fig. 1. Field plan of the experiment on Ranges 26 and 27 in Block 2 of the Fertility Field, University of Manitoba, in 1956 and 1957.

The plots on Range 27 received manure at the rate of 4 tons per acre prior to growing a crop. The manure was applied in the fall of a fallow year and in the fall of a crop year, providing the plot was not to be fallowed the following year.

In 1932, the plots in Ranges 26, 27 and 28 were divided into two 1/80 acre plots to accommodate the use of commercial fertilizers. From 1932 to 1955, inclusive, the north half of each plot in both Ranges 26 and 27 received ammonium phosphate (11-48-0) fertilizer drilled in with the seed at the rate of 45 pounds per acre. During these years, the stubble crops appeared to lack nitrogen. In 1956 and 1957, ammonium nitrate-phosphate (27-14-0) fertilizer was applied at the rate of 160 pounds per acre on stubble crops in both Ranges 26 and 27 to overcome the nitrogen deficiency. The north half of all plots in first year crops still received ammonium phosphate (11-48-0) fertilizer at the rate of 45 pounds per acre.

The plots were sampled for moisture and nitrates at four locations in each half plot at seeding time (May 1), at harvest (Aug. 15) and at freeze-up (Oct. 15). The soil from each respective depth was combined to make five composite samples representing the depths 0-6, 7-12, 13-24, 25-36, and 37-48 inches. Since data obtained in October of 1956 indicated a high nitrate content at the four foot depth, several plots were sampled to a depth of six feet in 1957.

2. Determination of Consumptive Use and Moisture Storage.

The samples were oven-dried at 110°C. and the moisture content based on oven-dry weight of soil was calculated. The samples were ground to pass a 2 mm. sieve. The moisture equivalent was determined as outlined by Briggs and McLane (8). The procedure is as follows: