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

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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. <u>Determination of Consumptive Use and Moisture Storage.</u>

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:

Grind each soil to pass a 2 mm. sieve and add, in duplicate, a measured amount of each soil with the measuring can to each moisture equivalent box. Place the moisture equivalent boxes in a pan containing water to a depth of one centimeter and allow the samples to stand protected from evaporation for 24 hours or overnight. Place in a centrifuge and operate at a speed of 2440 r.p.m. for 40 minutes. Transfer the soil to weighing cans after which the moisture determinations are made in the usual way.

The wilting percentage was calculated by dividing the moisture equivalent by 1.84 as proposed by Briggs and Shantz (4). It has been shown by other workers such as Veihmeyer and Hendrickson (43), Staple and Lehane (38), and Work and Lewis (46), that the relationship of the moisture equivalent to the wilting percentage of fine textured soils ranges from 1.80 to 1.99.

The available moisture was calculated by subtracting the wilting percentage from the moisture percentage of the sample. The percent available moisture was converted to inches of water by using an apparent density of 1.17 which was determined by the method outlined by Russel and Balcerek (33).

The consumptive use values for the growing period were calculated by the following method:

available moisture in soil in the spring

<u>plus</u> rainfall between spring and harvest

<u>minus</u> available moisture in soil at harvest.

Storage of moisture was calculated as the difference in the available moisture at any sampling dates which were being compared.

3. Determination of Nitrate-nitrogen in Soil.

Nitrate-nitrogen was determined by the colorimetric phenoldisulphonic method described by Harper (19) with modifications as suggested by Roller and McKaig (31). The procedure is as follows:

Weigh out 25 gm. of oven-dry soil in a 400 ml. beaker. Add 100 ml. of 0.02 N. $CuSO_4$ solution to the beaker and stir to wet sample thoroughly. Add a teaspoon of charcoal (nitrate-free) and stir again. Allow to stand for 10 to 15 minutes and add 0.4 gm. of $Ca(OH)_2$ (nitrate-free) and stir the sample. Filter and transfer a 25 ml. aliquot to a 50 ml. beaker and evaporate to dryness. Add 2 ml. of phenoldisulphonic acid and allow to stand for 10 minutes or longer. Add about 30 ml. of distilled water and allow to stand for a time till residue dissolves or stir until residue goes into solution. Transfer the solution and the rinse to a 100 ml. volumetric flask. Add NH_4OH until color develops and fill to mark with distilled water. Read the percent transmission against a blank on the spectrophotometer at a wavelength of 415 mμ.

The calcium hydroxide used contained an appreciable amount of nitrates. These were destroyed by heating in a muffle furnace at 750°C. for two to three hours.

B. Results and Discussions

1. Precipitation Data.

The precipitation data for the years 1956 and 1957 are presented in Table 1. The precipitation data for the Winnipeg area were obtained from the Dominion Meteorological Reports, while the data of The University of Manitoba were obtained from the Plant Science Department of The University of Manitoba. The data recorded at the University, presented for the period April to October in both 1956 and 1957, were used in

Table 1.

Monthly precipitation in inches at the University of Manitoba, Fort Garry and Stevenson Airport, Winnipeg, in 1956 and 1957, and the mean monthly precipitation for Winnipeg for the years 1874 to 1957 inclusive.

Month	1956		1957		83 year mean
	Wpg.	U of M	Wpg.	U of M	Winnipeg
January	1.7	*	0.7	*	0.92
February	1.1	*	1.0	*	0.84
March	1.6	*	1.0	*	1.11
April	0.2	*	1.6	*	1.29
May	2.0	2.00	1.7	1.20	2.17
June	2.2	2.53	5.0	5.06	3.20
July	3.3	3.43	1.7	2.01	2.90
Aug. (1-15)	5.4 x	0.91	3.5 x	1.91	2.54
(16-31)		5.33		0.48	
September	0.8	0.48	2.4	2.59	2.19
Oct. (1-15)	2.0 x	0.40	1.2 x	1.13	1.42
(16-31)		2.20		0.0	
November	1.9	*	0.7	*	1.10
December	1.5	*	0.3	*	0.92
May 1 - Aug. 15		8.87		10.18	
Aug. 15-Oct. 15		6.21		4.20	
Total	23.7	15.08	20.8	14.38	20.49

* Precipitation was not recorded for these months.

x Precipitation figure is for the whole month.

calculating the consumptive use of water and storage efficiency.

The rainfall during the growing season May 1 to August 15 was 8.87 inches and 10.18 inches in 1956 and 1957, respectively. In 1956 the rainfall in May, June and July was almost equal to the 83 year mean for each month, respectively. In 1957, the rainfall in May and July was below the mean while in June it was 1.8 inches higher than the 83 year mean of 3.2 inches.

After harvest in 1956 an above average rainfall of 5.33 inches was recorded between August 16 and 31 but the September rainfall was below normal. The first part of October received little precipitation, but in the latter half of the month 2.2 inches of rain fell. The wet weather in the latter part of October prevented completion of sampling before freeze-up.

During the period August 15 to October 15 the precipitation was 6.21 inches in 1956 and 4.20 inches in 1957. During the winter months, October 15, 1956 to April 30, 1957, precipitation of 9.9 inches was recorded.

Table 1 shows that during the year 1956, the total precipitation of 23.7 inches was 3.2 inches greater than the 83 year mean, while for the year 1957 the total precipitation was 0.3 inches greater than the mean.

2. Consumptive Use of Water by Wheat

Table 2 shows the consumptive use of water in inches as affected by manure and fertilizer treatment when wheat is grown continuously and as first, second, and third crop after fallow. The consumptive use of water on fertilizer and manure treatments is usually greater than the consumptive use of water on the check in any particular crop year after fallow. Even though a variability in consumptive use of water is noted, the two-year mean values of the check plots, which range from 11.76 to

Table 2.

Consumptive use of water in inches as affected by manure and fertilizer treatment when wheat is grown continuously and as first, second, and third crop after fallow.

Rotation	Crop Year	Calendar Year	Treatments: Check	Fertilizer	Manure	Manure + fertilizer	Mean
Continuous		1956	12.86	12.91	13.89	14.39	13.51
		1957	12.42	14.54	13.32	13.81	13.52
		2 yr.mean	12.64	13.72	13.60	14.10	13.51
F-W-W-W	3rd	1956	9.45	12.54	13.03	13.37	12.10
		1957	12.90	13.18	14.32	14.12	13.63
		2 yr.mean	11.17	12.86	13.62	13.74	12.86
F-W-W-W	2nd	1956	11.22	11.08	14.82	12.21	12.33
		1957	12.50	14.29	11.18	13.98	12.98
		2 yr.mean	11.86	12.68	13.00	13.09	12.65
F-W-W-W	1st	1956	11.54	12.78	13.96	15.15	13.35
		1957	11.01	13.11	14.06	11.97	12.53
		2 yr.mean	11.27	12.44	14.01	13.56	12.94
F-W-W	2nd	1956	14.59	12.47	15.94	12.81	13.95
		1957	12.34	11.05	14.30	16.03	13.43
		2 yr.mean	13.46	11.76	15.12	14.42	13.64
F-W-W	1st	1956	15.12	13.19	13.12	12.30	13.43
		1957	11.97	12.60	15.62	16.18	14.09
		2 yr.mean	13.04	12.89	14.37	14.24	13.76
F-W	1st	1956	16.01	17.84	13.21	12.17	14.80
		1957	11.97	13.79	15.83	12.25	13.46
		2 yr.mean	13.99	15.81	14.52	12.21	14.13

15.81 inches, 13.00 to 15.12 inches, and 12.21 to 14.42 inches on the fertilizer, manure, and fertilizer plus manure treatments, respectively.

The crop year after fallow has an influence on the consumptive use of water among the respective rotations. The average data suggest that the consumptive use of water is less on first crop after fallow in a F-W-W-W rotation than in a F-W-W or a F-W rotation. Similarly, the consumptive use of water is less on second crop after fallow in a F-W-W-W rotation than in a F-W-W rotation.

It may also be observed that no conclusive difference in consumptive use of water between the respective years is evident even though 8.87 inches and 10.18 inches of rain fell during the growing season in 1956 and 1957, respectively. Since the crop received more rain in 1957 than in 1956, less moisture was taken from the soil during the 1957 growing season as compared to the 1956 growing season.

Table 3 shows the available moisture to a depth of 3 feet in May and August on cropped plots in 1956 and 1957. The available moisture in May of 1956 is considerably lower than the available moisture in 1957. The mean available moisture values in May of 1956 on Ranges 26 and 27 are 4.94, and 5.43 inches, respectively, while in 1957 on Ranges 26 and 27, the mean available moisture values are 5.72 and 6.64 inches, respectively.

The available moisture in August 1956 is below one inch in 13 of 28 plots, which indicates that at harvest most of these plots were quite dry in the top three feet. Presumably moisture content was sufficiently low that growth rate of the crop was reduced. However, since the plots were only sampled in May and August, it was not possible to determine how long there was a low soil moisture content or whether the yield of wheat was affected. The precipitation (Table 1) in June 1956 of 2.53 inches was 0.67

Table 3.

Available moisture in inches to a depth of 3 feet in May and August on cropped plots in 1956 and 1957.

1956			1957		
Plot	May	August	Plot	May	August
Range 26					
1-S	6.64	0.76	2-S	5.00	3.40
-N	6.93	-0.65	-N	5.29	3.05
3-S	6.26	0.20	3-S	3.74	1.92
-N	5.79	2.00	-N	4.20	3.35
4-S	4.41	-0.88	5-S	7.09	3.81
-N	3.61	0.70	-N	6.01	3.65
6-S	5.15	2.55	6-S	6.41	4.24
-N	6.15	2.59	-N	6.77	2.48
7-S	3.85	1.80	7-S	6.84	4.18
-N	3.50	1.25	-N	6.32	3.65
8-S	2.47	1.51	9-S	3.96	3.54
-N	4.43	1.13	-N	4.88	1.95
10-S	4.95	1.01	10-S	6.27	3.44
-N	5.13	1.47	-N	7.35	3.05
Mean	4.94	1.10		5.72	3.26

Range 27

1-S	6.29	2.32	2-S	8.48	2.46
-N	7.00	2.51	-N	4.68	2.95
3-S	6.25	2.29	3-S	7.56	3.56
-N	6.01	2.36	-N	8.31	2.86
4-S	5.96	0.70	5-S	7.08	2.06
-N	5.17	2.75	-N	8.55	2.74
6-S	4.93	0.11	6-S	4.23	3.02
-N	5.19	0.91	-N	5.83	3.06
7-S	5.38	0.87	7-S	6.94	3.06
-N	5.05	2.15	-N	7.37	3.92
8-S	4.23	0.96	9-S	7.57	3.76
-N	5.02	0.89	-N	3.99	2.09
10-S	4.93	0.60	10-S	6.11	3.41
-N	4.72	0.05	-N	6.28	2.55
Mean	5.43	1.39		6.64	2.96

inches below the mean, but in July the precipitation was 0.53 inches greater than the mean of 2.90. It is probable that the crop utilized most of the soil moisture in June, but in July the precipitation of 3.43 inches may have been sufficient for crop growth.

3. Effect of Fertility on Yield of Wheat.

The yield of wheat in bushels per acre grown as continuous and as first, second, and third crop after fallow under fertilizer and manure treatments is shown in Table 4. The crop year has a definite influence on the yield of wheat. This is indicated by a comparison of the two-year mean check yields on first year crop of 40.9 (F-W-W-W), 41.3 (F-W-W), and 41.6 (F-W) bushels, on second year crop of 26.6 (F-W-W-W) and 35.3 (F-W-W) bushels. Similar trends are noted on the fertilizer, manure, and fertilizer plus manure treatments.

Fertility is an important factor in increasing wheat yields. On continuous crop, the yield was increased from a two-year mean yield of 21.6 bushels on the check to two-year mean yields of 38.0, 39.3, and 40.0 bushels on the fertilizer, manure, fertilizer plus manure treatments, respectively. On third year crop, the yield was increased from a two-year mean yield of 19.6 bushels on the check to 34.6, 34.6, and 38.9 bushels on the fertilizer, manure, fertilizer plus manure treatments, respectively. Similar results are noted for second year crops and first year crops, but the increase in yield due to fertilizer and manure treatments are not as great as the increase in yield which occurred on third year crop and continuous crop.

Fertilizer and manure treatments have not only increased the yield of wheat with respect to the mean check yield, but also have decreased the yield difference between first year, second year, third year

Table 4.

Yield of wheat in bushels per acre as affected by fertilizer and manure treatments when wheat is grown continuously and as first, second, and third crop after fallow.

Rotation	Crop Year	Calendar Year	Treatments: Check	Fertilizer	Manure	Manure+ fertilizer	Mean
Continuous		1956	23.3	38.0	42.6	44.0	36.9
		1957	20.0	38.0	36.0	36.0	32.5
		2 yr.mean	21.6	38.0	39.3	40.0	34.7
F-W-W-W	3rd	1956	18.0	36.0	32.6	41.3	31.9
		1957	21.3	33.3	36.6	36.6	31.9
		2 yr.mean	19.6	34.6	34.6	38.9	31.9
F-W-W-W	2nd	1956	33.3	24.0*	41.3	36.0*	37.3
		1957	20.0	38.0	32.6	42.6	33.6
		2 yr.mean	26.6		36.9		35.9
F-W-W-W	1st	1956	37.3	41.3	53.3	54.0	46.4
		1957	44.6	44.6	49.6	49.6	47.1
		2 yr.mean	40.9	42.9	51.4	51.8	46.7
F-W-W	2nd	1956	41.3	41.3	49.3	48.0	44.9
		1957	29.3	40.0	32.6	42.6	36.1
		2 yr.mean	35.3	40.6	40.9	45.3	40.5
F-W-W	1st	1956	42.6	47.3	46.0	54.6	47.6
		1957	40.0	41.3	45.3	47.3	43.4
		2 yr.mean	41.3	44.3	45.6	50.9	45.5
F-W	1st	1956	41.3	51.3	46.6	57.3	49.1
		1957	42.0	42.6	36.6	38.6	39.9
		2 yr.mean	41.6	46.9	41.6	48.0	44.5

* Plots were not fertilized in 1956 and are not included in the mean.

and continuous wheat crops. A comparison of the two-year mean check yields, consisting of 19.6 and 21.6 bushels on the third year and continuous crops, 26.6 and 35.3 bushels on second year crops and 40.9, 41.3, and 41.6 bushels on first year crops, indicates that third year and continuous crops yielded 10.3 bushels less than second year crops, while second year crops yielded 10.4 bushels less than first year crops. A comparison of the two-year mean yields on the fertilizer treatments, consisting of 34.6 and 38.0 bushels on third year and continuous crops, 38.0 and 40.6 bushels on second year crops, 42.9, 44.3, and 46.9 bushels on first year crops, indicates that third year and continuous crops yielded 3.4 bushels less than second year crops, while second year crops yielded 5.0 bushels less than first year crops. Similar trends may be noted in comparison of the two-year mean yields of the manure treatment and manure plus fertilizer treatment.

Since the effects of weed population on the yield of wheat were not taken into consideration in this investigation, it is not possible to determine the extent of competition that occurred. Experiments conducted on the effects of weed populations on the yield of grain at The University of Manitoba* provide evidence that weeds can reduce grain yields considerably if they are not sprayed before the wheat reaches the 5-6 leaf stage. All plots in this experiment were sprayed in both 1956 and 1957 approximately three weeks after emergence. In 1956, the plots in the experiment were sprayed with 4 ounces of 2,4,D (amine) per acre on June 9. The date of emergence was May 20. In 1957, the plots were sprayed with 8 ounces of 2,4,D (amine) per acre on June 7. The date of emergence was May 17.

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* Mimeographed data, Department of Plant Science, The University of Manitoba.

The extent of weed growth on the plots after spraying was not noted with exception to Plot 10 in Ranges 26 and 27 which had a considerable growth of Lolium perene. Presumably, the yield of wheat was reduced to some extent due to competition from the Lolium grass.

4. Effect of Fertility on Efficiency of Water Use.

In order to evaluate the efficiency of water use under different levels of fertility and for different crop years, the evapotranspiration-grain ratios were calculated. Table 5 shows the evapotranspiration-grain ratios in pounds of water consumed per pound of grain produced as affected by fertilizer and manure treatment on wheat grown continuously and as first, second, and third crop after fallow.

The highest mean evapotranspiration-grain ratios occurred on the check plots of third year (2133) and continuous (2212) wheat. On these plots the efficiency of water use was increased considerably by the use of fertilizer and manure. The two-year mean evapotranspiration-grain ratios for the fertilizer, manure, and fertilizer plus manure treatment on the continuous wheat treatment were 1363, 1312, and 1341, respectively, while the two-year mean evapotranspiration-grain ratios for the fertilizer, manure, fertilizer plus manure treatment on third year crop after fallow were 1404, 1491, and 1338, respectively.

The second highest mean evapotranspiration-grain ratios occurred on the check plots of second year wheat of the F-W-W-W (1815) and F-W-W (1461) rotation. Here again, there is an increase in water use efficiency due to an increase in the level of fertility. The two-year mean evapotranspiration-grain ratios on fertilizer, manure, fertilizer plus manure treatments are 1419, 1324, and 1238, respectively, on the F-W-W-W rotation. The two-year mean evapotranspiration-grain ratios on the fertilizer, manure,

Table 5.

Evapotranspiration-grain ratios in pounds of water consumed per pound of grain produced as affected by fertilizer and manure treatments on wheat grown continuously and as first, second, and third crop after fallow.

Rotation	Crop Year	Calendar Year	Treatments: Check	Fertilizer	Manure	Manure + fertilizer	Mean
Continuous		1956	2080	1282	1229	1234	1456
		1957	2344	1444	1396	1448	1658
		2 yr.mean	2212	1363	1312	1341	1557
F-W-W-W	3rd	1956	1981	1315	1506	1221	1505
		1957	2286	1494	1477	1456	1678
		2 yr.mean	2133	1404	1491	1338	1591
F-W-W-W	2nd	1956	1270	1742*	1353	1280*	1311
		1957	2359	1419	1295	1238	1577
		2 yr.mean	1815		1324		1449
F-W-W-W	1st	1956	1166	1167	988	1059	1095
		1957	932	1109	1070	911	1005
		2 yr.mean	1049	1138	1029	985	1050
F-W-W	2nd	1956	1332	1139	1219	1007	1174
		1957	1590	1043	1655	1420	1427
		2 yr.mean	1461	1091	1437	1213	1300
F-W-W	1st	1956	1338	1052	1076	849	1078
		1957	1129	1152	1301	1291	1218
		2 yr.mean	1233	1102	1188	1070	1148
F-W	1st	1956	1462	1312	1068	801	1160
		1957	1076	1222	1633	1198	1282
		2 yr.mean	1269	1262	1350	999	1221

* Plots did not receive fertilizer in 1956 and were not included in the mean.

fertilizer plus manure treatments are 1091, 1437, and 1213, respectively in the F-W-W rotation.

In the first year wheat treatment there appears to be no difference in water use efficiency between the check, fertilizer, and manure treatments, but on the fertilizer plus manure treatment the water use is the lowest and most efficient as indicated by the low values of 985 (F-W-W-W), 1070 (F-W-W), and 999 (F-W).

In general, there is a greater water use efficiency on first year crops of the check treatments which are fallowed less frequently than on first year crops which are fallowed every second year. Fertilizer and manure treatments increase the water use efficiency in the continuous wheat, second, and third year wheat, whereas the treatments have little influence on water use efficiency in the first wheat crop after fallow.

In 1957, the entire crop including grain and straw was harvested and weighed. The evapotranspiration ratios in pounds of water per pound of dry matter produced were calculated and are presented in Appendix ii.

5. Yields, Consumptive Use and Water Use Efficiency for Corn, Oats and Barley.

The yields, consumptive use, and evapotranspiration-grain (or silage) ratios for continuous corn, oats, and barley for 1956 and 1957 are presented in Table 6. An increase in yield and a decrease in the evapotranspiration-grain (or silage) ratio on corn, oats, and barley may be noted on the fertilizer treatment in comparison to the check. The increase in yield of silage on continuous corn was 1.48 tons in 1956 and 5.6 tons in 1957. The decrease in evapotranspiration-silage ratio is 41 pounds in 1957. The consumptive use on the fertilizer treatment was 0.68 inches higher in 1956 and 1.66 inches lower in 1957 than the check.

Table 6.

Yields, consumptive use, and evapotranspiration grain (or silage) ratios of continuous corn, oats and barley in 1956 and 1957.

Treatment	1956 Yield	1956 Water Use	1956 ET* Ratio	1957 Yield	1957 Water Use	1957 ET°* Ratio
Continuous corn						
	tons	inches		tons	inches	
Check	5.97	13.68	259	6.3	14.26	256
27-14-0 @ 160 lb/ac.	7.45	14.34	218	11.9	12.60	119
Continuous oats						
	bu/ac	inches		bu/ac	inches	
Check	44.7	8.44	1258	50.6	12.68	1669
27-14-0 @ 160 lb/ac	44.7	7.43	1107	70.6	13.03	1229
Continuous barley						
	bu/ac	inches		bu/ac	inches	
Check	41.6	8.80	998	21.7	13.64	2967
27-14-0 @ 160 lb/ac	46.6	8.50	861	45.8	13.71	1412

* Evapotranspiration - grain (or silage) ratio.

In 1956, the yield of oats on the check was equal to the yield on the fertilizer treatment. The yield in 1957 was 20 bushels higher on the fertilizer treatment in comparison to the check yield. The yield of barley on the check treatment was 5.0 bushels lower than the fertilized treatment in 1956 and 24.1 bushels lower in 1957.

A comparison of the consumptive use of water on check and fertilized treatments on oats shows that 1.01 inches more water was utilized on the check in 1956, while in 1957 the fertilized oat crop utilized 0.35 inches more than the check. The consumptive use of water on check treatment of continuous barley was 0.30 inches higher and 0.07 inches lower than the fertilized treatment in 1956 and 1957, respectively.

The evapotranspiration-grain ratio was lower on the fertilizer treatment for oats and barley in 1956 and 1957. The evapotranspiration-grain ratio on the fertilizer treatment of oats was 151 pounds lower in 1956 and 440 pounds lower in 1957 than the check. The evapotranspiration-grain ratio on the fertilizer treatment for barley was 137 pounds lower in 1956 and 1555 pounds lower in 1957 than the check.

In 1957, it was noted that weed infestation on the check barley treatment was quite high while on the fertilizer treatment less weeds were noted (Fig. 2). The low barley yield of 21.7 bushels was probably caused by the weed infestation which occurred. Presumably, the fertilizer application provided available nutrients in sufficient quantities to enable the vigorous plants to overcome the competition of the weeds and eventually reduce the weed population.

6. Storage of Moisture

The summerfallow period begins in the fall, after the crop has been removed and continues until a year from the following spring and hence lasts

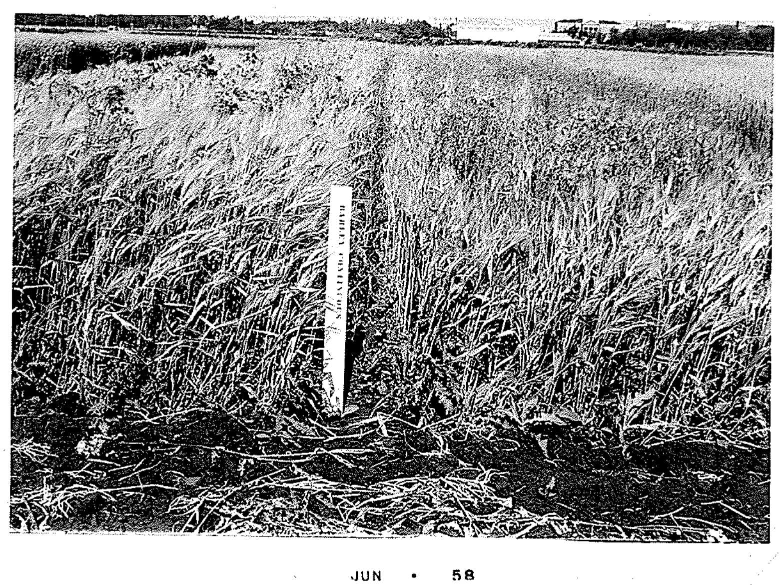

Fig. 2.

Barley plot showing the poor stand of barley and high weed infestation on the south half of the plot (on right).

about 21 months. Since the project was begun in May 1956 and terminated in October 1957, data was not obtainable for one complete summerfallow period. Moisture data was obtained for the plots fallowed in 1956 from May 1956 to May 1957. For plots fallowed in 1957, moisture data was obtained from August 1956 until October 1957.

In Table 7, the available moisture in inches to a four foot depth on fallow plots is presented for May, August and October of 1956 and 1957. The mean available moisture for plots 2, 5 and 9 was 5.76 inches in May of 1956 and 7.65 inches in May of 1957.

A loss of moisture during the period May 1956 to August 1956 occurred on all plots except 2-S in Range 26 and 2-N in Range 27 which showed a gain in moisture of 2.93 and 5.02 inches, respectively. This loss is indicated by the decrease in the available moisture from a mean of 5.76 in May to a mean of 4.48 in August. Thus, a loss of 1.28 inches of water occurred even though 8.87 inches of rain fell during this period. This loss between May and August was probably due to downward movement in the soil profile and to loss by evaporation. It may be observed that the available moisture in May of both 1956 and 1957 was quite high and near to the field capacity. Over a period of several months some of this moisture may have moved downward in the profile. Even though a soil may be at or near its field capacity shortly after a rain, its moisture content is not constant but slowly decreases with time, and moves downward in the profile. In addition to downward movement, evaporation may remove a large portion of the moisture from the evaporation zone.

Mean gains in water content of 1.92 and 1.25 inches occurred from August to October and October to May, respectively, maintaining a mean available moisture level of 6.40 inches in October and 7.65 inches

Table 7.

Available moisture in inches to a four foot depth in fallow plots in May, August, and October of 1956 and 1957.

	1956			1957		1956		1957		
Plot	May	August	October	May	Plot	August	October	May	August	October
					Range 26					
2-S	9.16	3.82	6.78	6.78	1-S	1.26	6.43	9.89	6.86	7.95
-N	7.50	3.27	7.21	7.21	-N	0.00	7.29	8.05	6.51	8.26
5-S	5.12	4.78	4.77	7.42	4-S	0.29	6.37	6.73	8.22	8.74
-N	7.16	5.89	5.10	7.68	-N	1.37	2.87	8.03	7.38	8.69
9-S	5.95	4.06	5.05	5.61	8-S	2.48	2.50	6.49	7.56	8.50
-N	5.03	3.57	6.81	6.22	-N	1.91	2.70	7.95	7.32	8.70
					Range 27					
2-S	3.22	8.24	7.43	9.99	1-S	3.75	4.95	8.94	6.89	8.12
-N	5.29	8.22	8.38	7.12	-N	4.14	5.79	10.41	7.44	8.92
5-S	5.51	3.21	6.94	8.81	4-S	0.76	6.57	8.43	7.90	8.70
-N	5.50	2.07	5.54	10.19	-N	3.01	7.22	9.04	7.23	5.76
9-S	4.77	2.93	*	9.48	8-S	1.11	*	9.07	7.96	9.19
-N	4.97	3.09	*	5.40	-N	1.38	*	9.55	8.78	8.25
Mean	5.76	4.48	6.40	7.65		1.78	5.27	8.55	7.50	8.31

* Plots were not sampled in 1956.

in May. During the period August to October and October to May, the precipitation was 6.21 and 9.9 inches, respectively. The data show that in the summerfallow period, between May 1956 and May 1957, there was a mean gain of water in the soil of 1.89 inches. This was 7.05 percent of the 24.98 inches of precipitation that fell during this period (Table 8).

For plots fallowed in 1957 there was, at the beginning of the fallow period August 1956, an available moisture content ranging from 0.0 to 4.14 inches with a mean of 1.78 inches. The mean available moisture increased to 5.27 inches by October, showing that the soil stored a mean of 3.49 inches from a rainfall of 6.21 inches. In the period October to May, the mean available moisture increased from 5.27 inches to 8.55 inches, indicating a gain of 3.28 inches from a precipitation of 9.9 inches. In the period August to October, the percent storage is 56.2 percent of the precipitation, while in the period October 1956 to May 1957 the storage was 33.1 percent of the precipitation.

Similar results were obtained during the summer of 1957 as in the summer of 1956. The mean available moisture in May 1957 was 8.55 inches and in August the mean was 7.50 inches, indicating that a mean loss of 1.05 inches of water occurred. During this period the precipitation was 10.18 inches. The mean available moisture in October was 8.31 inches, which shows that from August to October a mean gain of 0.81 inches of water occurred from a precipitation of 4.20 inches. The storage was 19.3 percent of the precipitation. The storage from August 1956 to October 1957 was 6.53 inches or 21.0 percent of the precipitation of 30.49 inches. The mean available moisture value at October 1957 of 8.31 inches indicates that the soil was near its field capacity.

Table 8.

Storage of moisture, rainfall, and percent storage on fallow plots in 1956 and 1957.

	Fallow 1956				Fallow 1957				
	May to Aug.	Aug. to Oct.	Oct. to May	May '56 to May '57	Aug. '56 to Oct. '56	Oct. to May	May to Aug.	Aug. to Oct.	Aug. '56 to Oct. '57
Moisture Stored	-1.28	1.92	1.25	1.89	3.49	3.28	-1.05	.81	6.53
Rainfall	8.87	6.21	9.9	24.98	6.21	9.9	10.18	4.20	30.49
Percent Storage	- -	31.0	12.6	7.0	56.2	33.1	- -	19.3	21.0

The data for the fallow periods in 1956 and 1957 show that the main portion of the total moisture stored during a fallow period occurs in the first fall and winter and the remaining portion is stored in the following fall and winter. During the summer months a decrease of moisture can be expected if the moisture in the spring of a fallow year is quite high.

Table 9 shows the available moisture in inches to a four foot depth on stubble plots in May, August and October of 1956 and 1957. The gains in moisture from August to October and October to May are similar to the gains shown for plots 1, 4 and 8 during the same period (Table 7). The mean available moistures in August 1956 and October of 2.32 and 5.66 inches, respectively, indicate a gain of moisture of 3.34 inches during this period. The mean available moisture in May 1957 indicates a further mean gain of 2.23 inches between October and May, resulting in a final mean available moisture content of 7.89 inches.

The mean available moisture of 7.89 and 4.72 inches in May and August 1957, respectively, shows that 3.17 inches were removed from the soil for crop use. Between August and October the mean gain was 0.88 inches.

7. <u>Nitrate Accumulation and Leaching in Soils.</u>

In 1957, the conditions were not very favourable for nitrate accumulation. The relatively high moisture content in spring and the above normal rainfall during the growing season, especially in June, was conducive to low soil temperatures.

Table 10 shows the nitrate-nitrogen in pounds per acre to a depth of three feet on summerfallow as influenced by fertilizer and manure treatments and cropping sequence in 1957. The data indicate that frequent

Table 9.

Available moisture in inches to a four foot depth on stubble plots in May, August, and October in 1956 and 1957.

	1956			1957		
Plot	May	August	October	May	August	October
Range 26						
3-S	7.96	1.71	5.98	5.13	2.97	6.71
-N	7.27	2.95	6.20	5.50	4.63	5.31
6-S	6.70	4.03	5.50	8.22	5.90	6.32
-N	7.57	3.66	5.47	8.15	4.04	4.71
7-S	5.03	2.68	5.63	8.37	5.65	5.48
-N	4.72	2.51	5.01	8.21	5.21	5.52
10-S	5.89	1.90	4.45	7.31	5.07	5.16
-N	6.13	2.09	4.60	9.01	4.65	4.27
Range 27						
3-S	7.87	3.62	7.27	9.53	5.41	- -
-N	6.95	3.52	6.53	10.57	4.72	- -
6-S	6.18	1.09	*	5.52	4.52	6.22
-N	7.27	.99	*	7.95	4.15	5.14
7-S	7.36	1.43	*	8.35	4.21	6.91
-N	6.61	3.27	*	9.21	5.27	7.07
10-S	6.24	1.22	*	7.72	5.21	4.28
-N	5.94	.42	*	7.59	3.96	5.41
Mean	6.61	2.32	5.66	7.89	4.72	5.60

* Not sampled due to wet weather.

Table 10.

Nitrate-nitrogen in pounds per acre to a depth of three feet on summerfallow as influenced by fertilizer and manure treatment and cropping sequence in 1957.

Treatment	May	August	October	Increase May to October
F-W Rotation				
Check	3.6	12.7	34.5	30.9
Fertilizer	4.3	10.6	26.9	22.6
Manure	9.8	21.6	49.1	39.3
Fertilizer plus manure	5.7	26.5	45.4	39.7
F-W-W Rotation				
Check	19.4	25.6	15.5	-3.9
Fertilizer	12.8	26.2	43.2	30.4
Manure	15.2	48.9	72.3	57.1
Fertilizer plus manure	9.4	66.7	58.3	48.9
F-W-W-W Rotation				
Check	0.0	29.8	49.5	49.5
Fertilizer	4.3	29.2	44.4	40.1
Manure	6.3	76.9	83.0	76.7
Fertilizer plus manure	15.3	84.5	66.4	51.1

fallowing results in a decrease in nitrate formation in the fallow year. Less nitrates were produced in the F-W rotation than in the F-W-W rotation. The highest nitrate contents occurred in the F-W-W-W rotation.

The largest increase in nitrate-nitrogen occurred on the manure treatment in the F-W-W and F-W-W-W rotations with gains of 57.1 pounds and 76.7 pounds of nitrogen, respectively.

Since frequent fallowing results in lower nitrate formation in the fallow year, it may be assumed that fertility is decreasing on the F-W rotation more rapidly than on the F-W-W or F-W-W-W rotations. Such a decrease in fertility, if it occurs, should be conducive to lower yields. A comparison of the mean yields for the ten year period 1948 to 1957 (Table 11) indicates that frequency of fallow has little or no effect on yield of wheat on fallow where the land is not manured, whereas on the manured plots, less frequent fallowing results in higher yields.

Table 11.

Mean yields of wheat for the ten year period 1948 to 1957 on first year crop after fallow as influenced by frequency of fallow at different fertility levels.

	Non-manured		Manure @ 4 tons/acre	
Rotation	Check	11-48-0 @ 45 lbs/ac.	Check	11-48-0 @ 45 lbs/ac.
F-W	32.9	38.9	34.3	38.5
F-W-W	32.3	37.4	38.2	41.9
F-W-W-W	31.6	37.9	41.2	44.6

Table 12 shows the nitrate-nitrogen content below the root zone which has probably accumulated over a period of years. The concentration

Table 12.

Nitrate-nitrogen content in the 37-72 inch depth in May, August, and October in 1957.

Plot	May	August	October
	Nitrate-nitrogen in ppm.		
		Range 26	
3-S	22.5	32.6	28.8
-N	23.3	20.0	44.1
4-S	24.2	11.1	11.2
-N	5.1	7.5	7.9
5-S	6.1	7.8	10.3
-N	10.0	8.6	12.6
9-S	18.4	15.1	14.0
-N	5.0	4.8	18.1
10-S	2.5	5.9	9.3
-N	2.3	4.8	5.2
Mean	11.9	11.8	16.1
		Range 27	
3-S	22.5	28.0	32.9
-N	15.7	17.9	23.4
4-S	17.6	19.2	16.4
-N	6.0	6.2	6.6
5-S	7.2	6.1	6.3
-N	20.0	18.9	16.6
9-S	16.8	24.5	32.2
-N	33.9	38.5	37.7
10-S	19.6	19.0	33.5
-N	11.2	8.3	13.5
Mean	17.0	17.6	21.9

in the 37 to 72 inch depth in May ranged from 2.3 to 33.9 ppm. of nitrate-nitrogen with a mean of 17.0 ppm. This is equivalent to a mean of about 160 pounds of nitrogen per acre for the three foot depth of soil.

Since little or no nitrate is produced below the root zone, the accumulation must be due to leaching of nitrates from the soil surface. Between the dates May and August, there has been slight losses on some plots and slight gains on other plots but the mean nitrate-nitrogen concentration is 17.6 ppm. indicating a slight gain. Between August and October, a gain in nitrogen occurred in 13 of 20 plots while a slight loss occurred in four plots. The mean gain of 4.3 ppm. of nitrate-nitrogen from August to October showed that nitrates have leached down and have accumulated below the root zone. The increase of nitrate content has occurred on plots which were cropped in 1957. Plot 4 was fallow but shows no gain in nitrate content below the three foot depth.

Lateral movement of nitrate in the soil may have occurred on some plots as indicated in Table 12. A high nitrate content was present in the soil in plot 9-N in Range 27 in May, August and October. These were 33.9, 38.5, 37.7 ppm., respectively. Since the concentration was 19.0 ppm. at August and increased to 33.5 ppm. in plot 10-S, it is probable that this increase of nitrates occurred due to lateral movement in the soil. The concentration in plot 10-N is low in comparison to plot 10-S.

Fig. 3 shows the nitrate-nitrogen distribution on four summerfallow plots in August and October 1957. All graphs indicate that the nitrates accumulated in the first foot of soil during the summerfallow period have leached into the root zone in the period between August and October. During this period, August to October, 4.20 inches of precipitation were recorded

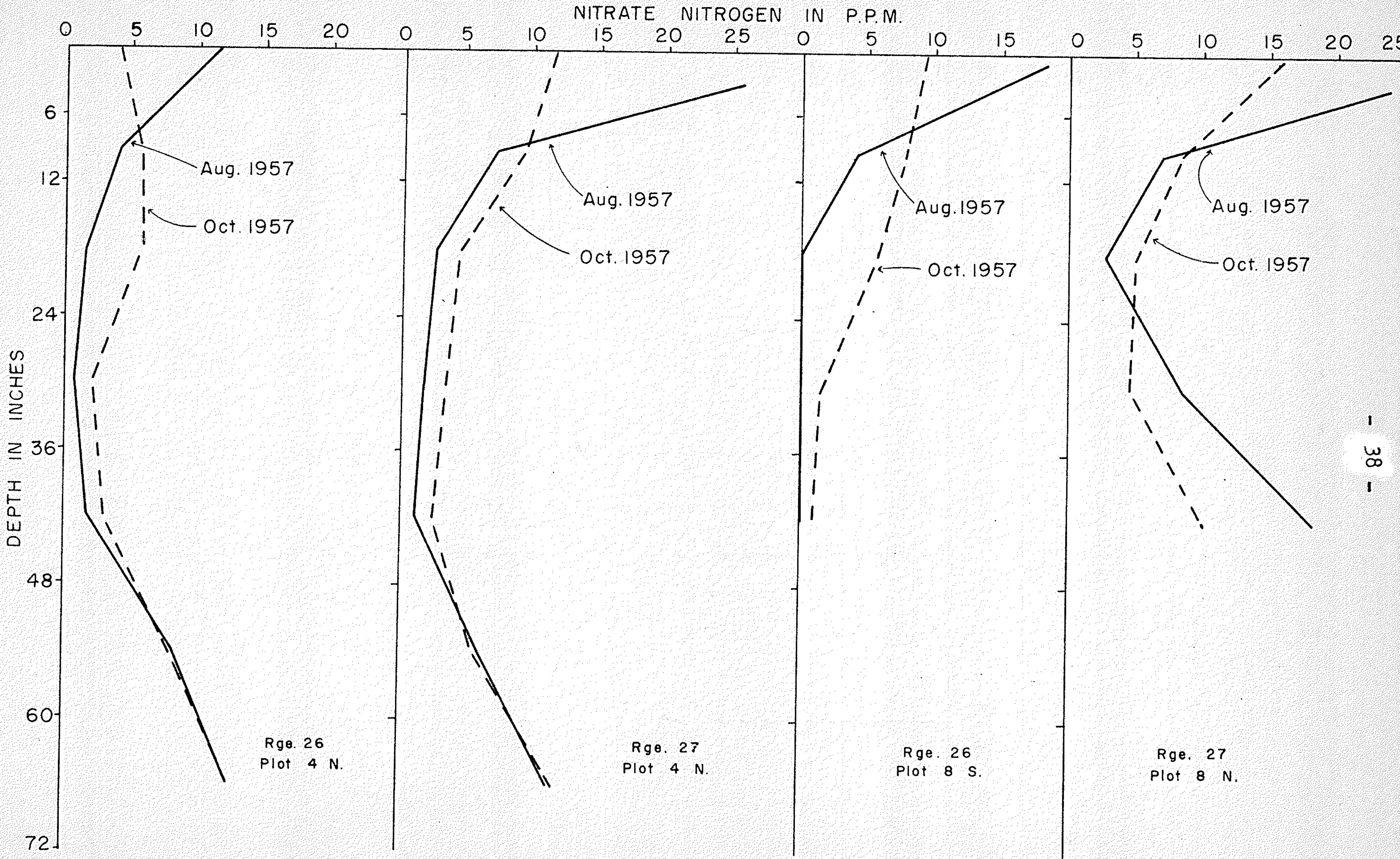

FIGURE 3 Nitrate nitrogen distribution in four summerfallow plots showing the leaching of nitrates between August and October 1957

(Table 1).

The graphs show that substantial nitrate losses may occur on summerfallow fields if sufficient rain falls to saturate the surface soil. Under fallow conditions, the soil contains a higher moisture content in comparison to cropped plots and therefore, becomes saturated more quickly if rains fall. Since nitrates are readily soluble, they will be carried downward into the root zone by percolating water. It has been previously shown (Table 12) that high nitrate contents have accumulated below the root zone.

IV. SUMMARY AND CONCLUSIONS

1. The crop year after fallow has no appreciable effect on the consumptive use of water by wheat on the check treatments. The consumptive use on the check treatments was 11.91, 12.66 and 12.93 inches on third year and continuous crop, second year crop and first year crop, respectively.

2. Fertilizer and manure treatment appeared to slightly increase consumptive use of water as compared to the check treatments.

3. The consumptive use of water in 1956 was similar to the consumptive use of water in 1957. The mean consumptive use values at The University of Manitoba indicate that 12.22 to 14.30 inches of water are required to produce a crop under weather conditions which occurred in 1956 and 1957.

4. The crop year after fallow has a definite influence on the yield of wheat on the check treatments. A decrease in yield of 10.4 bushels occurred on second year wheat crops in comparison to the first year wheat crop. A decrease in yield of 10.3 bushels occurred on third year and continuous crops in comparison to the second year crop.

5. Fertilizer and manure treatments have almost doubled the yield of wheat on third year and continuous crops in comparison to the check treatments and have substantially increased yield in the second year and first year crops.

6. Fertilizer and manure treatments decreased the yield difference between first year, second year, third year and continuous wheat.

7. Although the yield of third year and continuous wheat was almost doubled by the fertilizer and manure treatments, the yield was not as high as the yield on the check treatment of first year crop. Similarly,

on the fertilizer treatment and manure treatment on the second year crop, the yield was lower than on the check treatment of first year wheat.

8. Fertilizer and manure treatments increased the water use efficiency on second year, third year and continuous crops, whereas they had little effect on the water use efficiency of first year crops after fallow.

9. Fertilizer treatments increased the yield and water use efficiency on continuous corn, oats and barley.

10. During a summerfallow period, most of the moisture storage occurred in the first fall and winter and the remainder in the following fall and winter. During the summer months a decrease in soil moisture occurred. Results indicate that available moisture is sufficient in May to provide for the establishment of a crop. Sufficient rain falls during the growing season to insure a crop, but may not necessarily provide optimum conditions for crop growth.

11. Nitrate accumulation during a fallow year is less on plots which are fallowed every two years than plots fallowed once every three of four years.

12. Plots which received applications of manure accumulated more nitrates in the summerfallow period than unmanured plots.

13. High nitrate contents were found below the root zone.

14. Lateral movement of nitrate below the root zone may occur.

15. Leaching of nitrates may be considerable on fallow plots during a summerfallow period if the soil is quite moist and sufficient rain falls to saturate the soil surface.

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APPENDIX i

Yield, consumptive use, and evapotranspiration ratio of wheat as influenced by cropping sequence and fertilizer and manure treatments in 1956.

Rotation		No Manure Applied - Range 26						Manure Applied - Range 27					
		Check			Fertilized			Check			Fertilized		
	Year after fallow	Yield bu/ac.	H_2O used in inches	Evapo-trans. ratio	Yield bu/ac.	H_2O used in inches	Evapo-trans. ratio	Yield bu/ac.	H_2O used in inches	Evapo-trans. ratio	Yield bu/ac.	H_2O used in inches	Evapo-trans. ratio
F-W	1st	41.3	16.01	1462	51.3	17.84	1312	46.6	13.21	1068	57.3	12.17	801
F-W-W	1st	42.6	15.12	1338	47.3	13.19	1052	46.0	13.12	1076	54.6	12.30	849
	2nd	41.3	14.59	1332	41.3	12.47	1139	49.3	15.94	1219	48.0	12.81	1007
F-W-W-W	1st	37.3	11.54	1166	41.3	12.78	1167	53.3	13.96	988	54.0	15.15	1059
	2nd	33.3	11.22	1270	24.0	11.08	1742	41.3	14.82	1353	36.0	12.21	1280
	3rd	18.0	9.45	1980	36.0	12.54	1315	32.6	13.03	1506	41.3	13.37	1221
Cont. Wheat		23.3	12.86	2080	38.0	12.91	1282	42.6	13.89	1229	44.0	14.39	1234
Cont. Corn		5.97T	13.68	259	7.45T	14.34	218						
Cont. Oats		44.7	8.44	1258	44.7	7.43	1107						
Cont. Barley		41.6	8.80	988	46.6	8.50	861						

APPENDIX ii

Yield, consumptive use, and evapotranspiration ratio of wheat as influenced by cropping sequence and fertilizer and manure treatments in 1957.

		No Manure Applied - Range 26.								Manure Applied - Range 27							
Rotation		Check				Fertilized				Check				Fertilized			
	year after fallow	Yield bu/ac.	H_2O used in inches	E.T. Ratio Wheat	E.T. Ratio Wheat & Straw	Yield bu/ac.	H_2O used in inches	E.T. Ratio Wheat	E.T. Ratio Wheat & Straw	Yield bu/ac.	H_2O used in inches	E.T. Ratio Wheat	E.T. Ratio Wheat & Straw	Yield bu/ac.	H_2O used in inches	E.T. Ratio Wheat	E.T. Ratio Wheat & Straw
F-W	1st	42.0	11.97	1076	413	42.6	13.79	1222	465	36.6	15.83	1633	574	38.6	12.25	1198	428
F-W-W	1st	40.0	11.97	1129	429	41.3	12.60	1152	440	45.3	15.62	1301	433	47.3	16.18	1291	432
	2nd	29.3	12.34	1590	635	40.0	11.05	1043	381	32.6	14.30	1655	663	42.6	16.03	1420	515
F-W-W-W	1st	44.6	11.01	932	366	44.6	13.11	1109	403	49.6	14.06	1070	375	49.6	11.97	911	326
	2nd	20.0	12.50	2359	956	38.0	14.29	1419	532	32.6	11.18	1295	472	42.6	13.98	1238	430
	3rd	21.3	12.90	2286	890	33.3	13.18	1494	533	36.6	14.32	1477	533	36.6	14.12	1456	487
Cont. Wheat		20.0	12.42	2344	764	38.0	14.54	1444	521	36.0	13.32	1396	496	36.0	13.81	1448	528
Cont. Corn		6.3T	14.26	256		11.9T	12.60	119									
Cont. Oats		50.6	12.68	1669	764	70.6	13.03	1229	512								
Cont. Barley		21.7	13.64	2967	965	45.8	13.71	1412	562								

APPENDIX iii

Nitrate-nitrogen in ppm. for the respective plots and depths in October, 1956 and May, August and October, 1957.

Range 26				Plot &	Range 27			
1956	1957			Depth	1956	1957		
Oct.	May	Aug.	Oct.	1-S	Oct.	May	Aug.	Oct.
0.6	1.2	3.8	6.8	0-6	1.0	1.8	3.6	12.4
0.6	1.1	2.5	5.2	7-12	1.5	1.8	3.8	12.1
--	--	0.8	3.5	13-24	--	1.2	1.6	3.2
--	--	--	1.4	25-36	3.7	--	1.4	1.5
0.7	2.5	--	1.6	37-48	12.4	9.3	5.8	7.8
				1-N				
1.2	1.5	1.6	5.4	0-6	0.8	1.2	5.7	10.4
0.5	1.2	1.8	4.2	7-12	0.8	0.8	2.3	10.2
--	--	1.1	2.6	13-24	--	0.8	1.8	1.7
--	--	0.5	1.1	25-36	2.1	--	2.5	2.3
1.1	--	1.9	0.7	37-48	10.0	1.3	7.7	10.2
				2-S				
3.7	4.2	--	1.2	0-6	5.6	4.7	0.7	3.8
2.9	4.8	--	0.8	7-12	7.2	4.8	--	2.9
3.3	3.5	--	1.1	13-24	8.3	1.4	0.6	2.1
3.7	3.3	1.8	3.8	25-36	9.8	6.0	17.2	14.6
8.5	9.1	7.4	9.7	37-48	16.6	10.7	22.7	20.8
				2-N				
5.5	4.5	--	1.2	0-6	10.0	3.7	1.2	5.6
5.6	7.2	--	1.3	7-12	11.1	6.0	--	3.8
4.2	4.6	4.8	--	13-24	6.5	8.9	--	0.6
3.2	7.3	9.9	3.8	25-36	11.9	9.3	10.4	9.7
11.5	7.3	13.3	10.6	37-48	25.9	28.5	22.4	12.1

Range 26				Plot &	Range 27			
1956	1957			Depth	1956	1957		
Oct.	May	Aug.	Oct.	3-S	Oct.	May	Aug.	Oct.
1.3	1.6	2.4	2.3	0-6	2.2	4.2	4.1	6.9
1.0	1.3	--	1.0	7-12	2.7	4.5	0.7	4.0
1.8	2.4	--	--	13-24	2.7	1.7	--	2.1
12.4	4.4	9.9	4.6	25-36	11.9	7.8	7.4	9.7
17.5	8.8	24.0	22.0	37-48	27.1	14.6	20.4	29.7
	29.4	36.1	31.3	49-60		27.2	31.0	36.4
	29.4	37.7	33.3	61-72		24.7	32.2	32.6
				3-N				
2.9	2.9	2.2	2.6	0-6	1.9	1.9	2.9	7.1
1.7	1.6	--	2.4	7-12	1.9	2.7	1.0	5.9
5.9	2.0	--	5.4	13-24	0.8	2.0	--	2.5
14.6	9.4	--	6.8	25-36	5.4	1.3	--	0.6
39.0	16.6	11.8	26.5	37-48	12.8	4.4	7.0	12.8
	25.9	17.9	58.5	49-60		23.5	22.4	30.6
	27.5	30.3	47.3	61-72		19.1	24.3	26.8
				4-S				
3.9	2.3	5.9	1.9	0-6	2.4	1.1	13.5	13.5
1.4	0.7	3.3	2.7	7-12	0.8	1.1	7.5	9.9
0.8	0.8	1.8	1.6	13-24	1.0	0.9	2.6	6.3
12.8	3.8	1.6	1.0	25-36	4.2	2.8	2.3	4.8
20.5	21.7	5.1	5.0	37-48	8.9	9.0	9.4	8.7
	24.6	14.0	11.2	49-60		19.5	23.3	20.1
	26.5	14.2	17.3	61-72		24.3	24.9	20.5
				4-N				
2.7	2.1	9.0	4.7	0-6	2.2	1.6	25.5	11.0
1.2	1.4	4.0	5.8	7-12	1.6	1.5	7.3	9.5
--	1.0	1.6	5.8	13-24	--	1.4	2.7	4.6
--	1.3	0.9	2.6	25-36	--	--	1.8	3.5
0.6	--	1.7	3.0	37-48	2.4	1.1	1.2	2.6
	6.2	8.4	8.1	49-60		5.8	6.1	5.7
	9.3	12.4	12.5	61-72		11.3	11.3	11.6

Range 26				Plot &	Range 27			
1956:	1957			Depth	1956:	1957		
Oct.:	May	Aug.	Oct.		Oct:	May	Aug	Oct.
				5-S				
7.6	2.6	1.2	1.9	0-6	3.7	2.8	2.8	4.5
2.9	3.6	--	0.7	7-12	3.7	2.0	0.5	3.5
1.7	4.4	--	--	13-24	2.9	3.9	--	0.6
1.9	2.9	0.9	--	25-36	1.9	4.2	--	--
7.6	2.0	3.8	3.4	37-48	2.2	4.4	1.8	2.4
	6.1	9.4	11.5	49-60		6.3	6.9	5.4
	10.1	10.4	16.1	61-72		10.8	9.5	11.0
				5-N				
3.5	2.7	1.4	3.6	0-6	5.6	5.8	2.9	3.8
2.3	3.5	0.9	2.9	7-12	4.8	5.9	0.7	1.9
1.9	3.0	0.8	0.9	13-24	2.9	4.3	--	--
2.9	1.7	0.5	--	25-36	3.8	7.5	4.2	2.1
7.4	3.0	1.9	3.7	37-48	5.8	14.6	11.5	10.8
	10.8	10.4	13.7	49-60		20.7	24.3	15.7
	16.3	13.8	20.1	61-72		24.3	21.1	23.6
				6-S				
1.6	2.1	0.7	1.6	0-6		4.0	2.0	4.0
0.7	2.0	--	0.8	7-12		2.4	--	2.9
--	--	--	--	13-24		1.9	--	--
--	1.4	--	--	25-36		4.4	2.1	--
4.5	5.6	1.1	4.6	37-48		6.0	10.9	6.7
				6-N				
1.2	2.7	1.1	2.8	0-6		2.7	2.9	6.8
0.6	3.2	--	1.2	7-12		1.9	1.1	3.9
--	1.6	--	--	13-24		0.7	--	0.8
1.0	--	--	--	25-36		--	--	--
7.3	1.9	--	1.4	37-48		2.5	2.0	2.9
				7-S				
1.7	2.2	1.3	2.0	0-6		2.0	2.9	4.6
1.6	2.5	--	1.2	7-12		2.5	0.8	3.0
0.6	1.3	--	--	13-24		--	--	--
1.7	0.7	--	--	25-36		0.9	--	--
10.4	4.9	1.2	3.0	37-48		1.9	2.6	2.2

Range 26				Plot &	Range 27			
1956	1957			Depth	1956	1957		
Oct.	May	Aug.	Oct.	7-N	Oct.	May	Aug.	Oct.
1.2	- -	0.5	2.0	0-6		2.8	1.9	3.5
0.8	- -	- -	1.2	7-12		1.2	0.7	2.9
- -	- -	- -	- -	13-24		0.8	- -	1.1
- -	- -	- -	- -	25-36		0.6	- -	- -
- -	1.6	- -	- -	37-48		- -	- -	- -
				8-S				
1.0	- -	14.6	8.4	0-6		1.8	21.4	21.1
0.8	- -	4.1	7.8	7-12		2.2	11.2	16.0
- -	- -	- -	5.8	13-24		- -	5.8	5.0
- -	- -	- -	1.7	25-36		- -	2.0	2.6
2.2	1.0	- -	1.0	37-48		5.2	2.7	3.9
				8-N				
0.8	1.4	10.6	5.0	0-6		2.9	23.7	13.6
- -	1.3	2.8	5.0	7-12		2.4	6.8	8.3
- -	- -	0.8	2.3	13-24		2.1	2.7	5.2
- -	- -	1.7	6.6	25-36		- -	8.5	4.7
3.5	2.9	4.1	11.1	37-48		2.1	18.2	10.0
				9-S				
5.9	2.2	2.4	3.3	0-6		4.7	2.8	5.3
6.3	1.4	1.1	1.7	7-12		3.6	1.0	3.7
2.9	3.2	0.7	- -	13-24		4.2	- -	0.9
4.5	3.2	0.8	2.3	25-36		5.0	6.5	1.8
17.9	13.7	5.3	10.4	37-48		10.6	19.5	24.2
	26.2	19.8	14.7	49-60		22.3	37.1	41.6
	15.6	20.1	17.0	61-72		17.0	17.0	30.3
				9-N				
5.4	3.1	1.6	2.7	0-6		3.6	3.5	9.3
5.0	2.4	- -	1.9	7-12		2.4	1.1	6.9
3.0	3.2	- -	0.9	13-24		6.9	0.8	3.2
1.7	2.4	- -	1.5	25-36		3.7	17.2	12.1
6.2	4.0	- -	10.3	37-48		28.4	36.4	22.7
	5.4	5.8	20.4	49-60		38.0	45.7	50.9
	5.6	8.8	23.7	61-72		35.5	33.3	39.6

Range 26				Plot &	Range 27			
1956	1957			Depth	1956	1957		
Oct.	May	Aug.	Oct.	10-S	Oct.	May	Aug.	Oct.
2.0	1.7	1.4	2.7	0-6		4.8	5.5	7.0
1.1	1.3	- -	2.0	7-12		3.3	1.6	5.1
1.8	1.0	- -	- -	13-24		3.1	0.8	1.6
22.7	0.8	- -	- -	25-36		11.8	8.6	25.9
25.2	- -	0.5	3.0	37-48		17.5	14.0	40.6
	2.6	7.0	11.0	49-60		25.2	22.0	30.3
	4.8	10.2	13.9	61-72		16.3	21.1	23.7
				10-N				
3.0	1.9	1.1	4.2	0-6		2.6	4.1	9.7
1.7	2.9	- -	3.2	7-12		1.6	0.9	6.1
- -	2.9	- -	- -	13-24		3.0	0.8	3.2
- -	0.8	- -	- -	25-36		6.9	3.1	16.6
- -	- -	6.4	- -	37-48		13.4	7.0	18.5
	1.8	2.2	4.8	49-60		5.9	7.6	11.3
	5.1	6.1	10.8	61-72		14.4	10.1	10.6
				11-S				
1.7	2.9		2.6	0-6		2.7	1.4	1.6
1.6	2.8		1.7	7-12		2.6	- -	- -
- -	- -		- -	13-24		1.9	- -	- -
- -	1.0		- -	25-36		1.8	1.6	2.0
3.5	1.7		2.5	37-48		6.1	9.3	5.9
				11-N				
1.6	2.9		2.2	0-6		2.7	1.4	1.3
0.7	2.7		1.6	7-12		1.6	- -	2.2
- -	- -		- -	13-24		1.3	- -	- -
1.4	- -		- -	25-36		1.3	1.0	- -
4.5	1.7		1.4	37-48		5.3	6.1	7.9

Range 28				Plot & Depth
1956	1957			
Oct.	May	Aug.	Oct.	11-S
	3.9	1.6	1.1	0-6
	3.1	- -	1.1	7-12
	1.2	- -	0.6	13-24
	0.9	2.2	0.6	25-36
	10.6	16.6	4.2	37-48
				11-N
	3.6	1.6	2.5	0-6
	3.6	- -	1.3	7-12
	1.1	- -	0.7	13-24
	- -	- -	0.7	25-36
	0.7	- -	1.6	37-48