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Factors Affecting The Accumulation of Nitrate Nitrogen in High Plains Soils

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FACTORS AFFECTING THE ACCUMULATION OF NITRATE NITROGEN IN HIGH PLAINS SOILS

H. H. FINNELL

INTRODUCTION

The manipulation of crop sequence, cultural practice, and fallow methods has been shown to exert a considerable influence on the quality and quantity of crops produced on heavy soils under semiarid conditions. No small part of these effects is due to the accumulations of nitrate nitrogen and their disposition relative to soil moisture and cropping.

In order to obtain information suitable for use in determining a standard farm practice which will enable the most efficient use to be made of nitrogen resources under the soil and climatic conditions of the High Plains of Oklahoma this study was undertaken at the Panhandle Agricultural Experiment Station beginning in 1923. The first report of this work covers an attempt to discover and analyze some factors which govern nitrate accumulations in the topsoil, and preliminary observations on the movement of nitrates in the soil.

Observations of the seasonal progress of nitrate accumulations in the area represented by these experiments suggest the possibility of using the soil nitrate content as a means of appraising current fertility conditions. Winter, being the normally dry season of the year when nitrification reaches a minimum, usually affords a period of several months duration in which nitrate content varies little. Observations during this time indicate somewhat accurately the net effects of the previous season's operations and the initial store of available nitrogen which will be used by the succeeding crop.

Limitations of This Study

The investigation of nitrate accumulations has been carried out without regard to the behavior of other plant food elements such as phosphorus and potassium and no account has been taken of parallel accumulations and possible joint effects in which these elements may be involved.

The questions of the extent to which nitrification should be encouraged and the best methods of utilizing nitrate stores have been left for further investigation.

Review of Literature

Scope. A study of the literature on nitrate problems shows without doubt that the relation of factors controlling nitrate formation varies sharply in different regions, particularly with reference to soil and climatic conditions. For example, what might be a decisively controlling factor in one place may be of small importance under a different set of conditions.

Literature on this subject is so extensive that a comprehensive review here would be impracticable. The references which have been selected are such as it was thought would be of interest in connection with a study of the nitrate problem in the Panhandle of Oklahoma.

Effects of Cropping. Albrecht (1) in Missouri noted that cropped land failed to accumulate nitrates after growth was advanced.

Buckman (4) in Montana found that under dry farming conditions fallowing increased soil moisture and nitrates which were not fully depleted by the growing of row crops in preparation for small grains.

McBeth and Smith (12) observed that continuous cropping stimulated soils to a higher nitrifying power than fallowing, although crops removed the nitrate formed almost as rapidly as it accumulated. Ninety per cent of the nitrates formed in the five-foot soil section was produced within the upper 18 inches of soil. Nitrification ceased when the soil moisture fell below 5%.

Whiting and Schoonover (19), working in Illinois, observed that crop rotations containing heavy feeders in sequence permitted very little nitrate nitrogen to accumulate.

Blair and Prince (2) found the lowest nitrate content of their soils existed at the time of maturity of crops.

Effects of Tillage. Koch (11) found that nitrification was hastened by increasing the aeration of soil. Bacterial activity decreased to a depth of 80 centimeters.

Velbel (18), in connection with a study of the supply of organic matter, found early fallowing more favorable to nitrate accumulation than late.

Call (5) in Kansas reported that late preparation of the soil for wheat permitted a marked response of the soils to nitrate fertilizer, whereas land that was worked early in the season satisfactorily supplied the needs of the crop by nitrification of soil nitrogen. The method of culture did not affect nitrification as did the time of culture.

Call and Sewell (6) concluded from a study of cultural methods that weed control was the essential factor for maintaining optimum conditions for nitrate accumulation.

Albrecht (1) found no difference in nitrate in soils plowed four and eight inches deep, but land which was left uncultivated during the season contained more nitrate than that given frequent cultivation.

Sievers (17) states that both time and method of tillage affected moisture and nitrate stores in Washington.

Effect of Climatic Factors. Koch's (11) application of 4000 pounds of ammonia sulphate in November, one-half of which had been nitrified by the following year, showed considerable bacterial function during the winter season.

Peterson and Scott (14) in Victoria concluded from studies of varying moisture conditions that the moisture in the surface soil was a most important factor to nitrification and that the retarding of nitrate accumulation by crop growth was due both to the using up of nitrates present and the removal of moisture needed by soil organisms.

Whiting and Schoonover (19) from their studies designated the periods of most intensive nitrate production, namely, late spring with early summer and fall. Little nitrate was formed in midsummer and none in winter.

Russell and Richards (15) observed in England that the heavier losses of nitrates by soil leaching occurred in winters following hot summers and during seasons of wet weather. Dry weather served to increase nitrate accumulations both by avoiding leaching losses and by increasing the rate of nitrification.

Sievers' work (17) in Washington indicated that the greatest amount of nitrification took place where the highest soil moisture content was maintained the longest time during the warm season.

Blair and Prince (2) found that high nitrates did not insure high yields of crops and that nitrification became slower with the advent of cold weather.

Brown and Allison (3), studying the influence of some common humus forming materials on bacterial activity, found that those possessing a wide nitrogen-carbon ratio decreased the yield of the crop following immediately after their application, while narrow ratio substances increased the yield. Carbonaceous materials gave as good result with the second crop after application as did the nitrogenous materials. Animal material increased ammonification while leguminous materials increased nitrification most. Carbonaceous residues increased azofication most.

Murray (13) reported that additions of straw reduced soil nitrates, increased the bacterial population, and served to maintain the total nitrogen content.

Scott (16) reported observations of the decrease of nitrate formation in wheat soils to which applications of straw had been made.

Discussion of Literature. It is evident that cropping affects nitrate accumulation not only by removal of stores but also by the seasonal temperature-moisture relation which it establishes and the nature of the residues left in the soil.

There is some evidence in literature that the effects of tillage may be either favorable or unfavorable to nitrification, depending upon its relation to the existing complex of moisture, temperature and organic matter. It seems quite likely that optimum conditions of tillage would in most cases be found somewhere between the possible extremes of both timing and intensity.

It is clear that conditions which would be characterized as wet in one climate would be known as dry in another climate and that suitable temperatures for maximum nitrification are ordinarily experienced at different seasons of the year in different regions.

The period of nitrate depletion following applications of carbonaceous organic matter appears to depend for duration upon cultural, climatic and soil conditions which affect the rapidity of a restoration of the normal nitrogen-carbon ratio.

Soil Nitrate Studies at Goodwell, Oklahoma

The data on which this analysis is based were obtained from three series of plots located on heavy silt loam soil which are used for soil moisture studies and crop rotation experiments. A wide variety of cultural and cropping conditions are represented in these series which total 70 plots. Nitrate data are available on 22 of these plots for a period of eight years and on 48 plots for a period of five years. The cropping and soil conditions preceding and accompanying the soil sampling from which nitrate determination was made are indicated in Tables I to XVIII, inclusive.

Table XIX presents a summary of the climatic conditions found significant in this study for the period of eight years. The factors for which values are known include both field and climatic conditions other than those found significant in their relation to nitrate accumulations. A few factors not found to be highly significant are included in the present analyses because of considerable interest attached to them as a result of other work herein referred to.

Those factors investigated but discarded from the study because significant relationships were not discovered either in simple or multiple correlations, or which were displaced by other measurements having a bearing upon the same primary conditions, are as follows: Frequency of spring rains, frequency of summer rains, frequency of fall rains, average size of spring rains, average size of summer rains, average size of fall rains, summer mean temperature, fall mean temperature, average daily range of summer temperature, average daily range of fall temperature, topsoil moisture content in summer, cultural index (8), frequency of effective rains during previous year, and mean temperature variations for other periods particularly during the change of seasons.

In an exhaustive study of possible relations of temperature variations there was found no factor which could not be as well or better represented by directly associated or dependent conditions of greater significance to nitrate accumulations. Since none of the temperature factors served to decrease the error of estimate in the presence of what were considered more satisfactory measures, all of them were eliminated from the analysis as presented.

Methods of Obtaining Data Used

Y—Total Yield: The figures representing total yield are for pounds of air-dried crop material removed per acre during the previous year. In case of summer fallowing or crop failure the value has been zero. Where straw or stover has been removed in addition to grain and hay these were included as part of the total yield. All hay, fodder, and stover yields have been calculated to a 10% moisture content on the basis of moisture determinations made at the time of weighing. In short, this factor represents the total amount of air-dried plant material removed from the plot the year previous to the nitrate determination.

S—Cultivation: The kind and number of cultivations given during the previous year have been indicated by taking the sum of the depths cultivated for each plot. The average depths of soil stirred by the different types of cultivation were as follows:

Spike Tooth Harrowing	1 inch
Disk Drilling	1 inch
Spring Tooth Harrowing	2 inch
Leveling Listed Ridges	2 inch
Sweep Cultivating	2 inch
Disk Cultivating	3 inch
Listing	4 inch
Plowing	6 inch

Where an operation was performed within a very short time, as from one week to 10 days, previous to the nitrate sampling in January this tillage was credited to the succeeding year. Very few such instances have been observed, however, since the major part of all tillage was performed during the spring, summer and fall.

I—Time Interval Between the Last Previous Harvest and Nitrate Sampling: This factor, the rest period, has been expressed in months, using the nearest even month, and indicates roughly the period of time during which the soil has been free of crop growth permitting recovery of moisture and favorable fertility condition. There is this exception, however, that plots which had been seeded to winter wheat, usually in October, were counted as unoccupied up until January when soil samples were taken. There was considerable variation in fall growing conditions, the nitrate and moisture stores not being materially affected in some years, while in others considerable depletion was noted. Six of the 22 plots in series 1300 and 10 of the 48 plots in series 1100 and 1200 were affected in this way. This variation has largely been accounted for, however, by the factor J, the topsoil moisture passing the winter. Variation from the topsoil moisture content as recorded at frost and at midwinter has been largely due to the early stage crop growth of those plots seeded to wheat.

B—Topsoil Moisture at Frost: The moisture content of the first foot is indicated by the percentage of total moisture on a moisture free basis and represents the moisture content of the surface soil at the time of the first killing frost in the fall.

J—Topsoil Moisture Content Passing Winter: The soil moisture expressed as B was determined during late winter at the time when the first early spring growth started. The calendar date varied widely during the months of February and March on this determination, but it represents very fairly the topsoil moisture conditions just previous to the time considerable demands were first made by plant growth upon the moisture stores which were carried through the winter.

O—Raw Organic Matter Content of Topsoil: An estimate of the unincorporated organic matter was made upon the same samples used for nitrate determination taken early in January each year. The method used is described fully in another paper (7). This determination in brief represents an effort to separate by physical methods the particles of undecayed vegetable matter which had so far not undergone disintegration. The amount of raw organic matter is expressed in pounds per acre 6 inches of topsoil. Since the field technic of sampling has included specific care to exclude surface trash, this determination represents relatively fine particles of organic matter which, having been worked into the soil by previous cultivation, remained undecayed.

G—Number of Excessive Rains During the Previous Year: The rains classified as excessive were designated on the same basis as was used in a previous moisture study (8) and called class C rainfall. This factor in effect represents the number of times during the year sufficient surface moisture was present to permit runoff and consequently to afford a maximum moisture penetration of the soil for the duration of a day.

R—Earliness of Effective Rains: The distribution of effective rainfall during the previous year has been indicated by using the time interval expressed in months during which the last 2.95 inches effective rain fell. Effective rainfall is here defined as "K—Moderate Fraction of Rainfall" (8) which excludes showers too small to penetrate the mulch and that portion of excessive rains which is subject to loss by runoff. The arbitrary amount, 2.95 inches, represents the average amount of effective rainfall required to displace the normal soil moisture content of the topsoil, 0"-6." This factor brings into consideration in addition to the number of leaching rains experienced during the entire year the length of period immediately preceding the nitrate determination in which complete leaching of the topsoil has not occurred.

N—Nitrate Nitrogen: Nitrate nitrogen was determined by the official method adopted by the Association of Official Agricultural Chemists in samples made up of a composite of 6 to 15 tube cores, 0"-6," after immediate drying and pulverizing. All samplings were made during the early part of January. Nitrate nitrogen is expressed in parts per million of dry soil.

Table I.—Plot Conditions and Nitrate Nitrogen in Topsoil at Close of Year 1923

Number of Excessive Rains During the Year—7.
Months Previous to Nitrate Test in Which 2.95 Inches Effective Rain Fell—2.3

Plot Number	Previous Crop	Crop Grown 1923	Total Yield Lbs. Per Acre	Sum of Cultural Depths Per Year, Inches	Months from Last Harvest to Nitrate Sampling	Percentage of Soil Moisture at Frost 0"-6"	Percentage of Soil Moisture Passing Winter 0"-6"	Raw Organic Matter P. P. M. 0"-6"	Nitrate Nitrogen P. P. M. 0"-6"
1303	Fallow	Fallow	0000	12	30	22.90	19.52	500	21.97
1304	Fallow	Fallow	0000	12	30	22.25	19.75	600	7.68
1305	Fallow	Fallow	0000	16	30	21.61	19.47	675	25.79
1306	Fallow	Fallow	0000	16	30	22.25	18.19	800	33.50
1307	Fallow	Fallow	0000	16	30	22.25	18.96	750	20.93
1308	Fallow	Milo 3½'	1200	16	2	18.41	18.37	775	1.18
1309	Fallow	Milo 3½'	1200	13	2	19.68	18.96	800	1.08
1310	Fallow	Milo 3½'	1200	13	2	18.41	21.22	850	1.07
1311	Fallow	Milo 3½'	1200	15	2	18.41	14.92	850	.92
1312	Fallow	Milo 3½'	1200	15	2	18.41	16.23	850	.94
1313	Fallow	Milo 3½'	1200	17	2	18.41	17.61	625	3.89
1314	Fallow	Milo 3½'	1200	17	2	18.41	18.71	625	3.19
1315	Fallow	Milo 3½'	1200	17	2	18.20	18.05	700	1.38
1316	Fallow	Milo 3½'	1200	15	2	17.37	16.86	625	.57
1317	Fallow	Milo 3½'	1200	16	2	18.41	13.95	625	.85
1318	Fallow	Milo 3½'	1200	18	2	18.41	16.90	375	3.08
1319	Fallow	Milo 3½'	1200	17	2	18.41	15.88	625	.52
1320	Fallow	Milo 3½'	1200	18	2	18.41	16.65	450	.93
1321	Fallow	Milo 3½'	1200	8	2	18.41	17.43	625	1.34
1322	Fallow	Milo 3½'	1200	8	2	18.41	15.72	625	.81
1323	Fallow	Milo 3½'	1200	8	2	18.41	17.52	400	.87
1324	Fallow	Milo 3½'	1200	14	2	18.41	17.35	400	3.82

Table II.—Plot Conditions and Nitrate Nitrogen in Topsoil at Close of Year 1924

Number of Excessive Rains During Year—3.
Months Previous to Nitrate Test in Which 2.95 Inches Effective Rain Fell—5.5

Plot Number	Previous Crop	Crop Grown 1924	Total Yield Lbs. Per Acre	Sum of Cultural Depths Per Year, Inches	Months from Last Harvest to Nitrate Sampling	Percentage of Soil Moisture at Frost 0"-6"	Percentage of Soil Moisture Passing Winter 0"-6"	Raw Organic Matter P. P. M. 0"-6"	Nitrate Nitrogen P. P. M. 0"-6"
1303	Fallow	Wheat	3570	6	6	15.11	12.56	475	13.20
1304	Fallow	Wheat	4550	1	6	12.57	13.06	650	7.52
1305	Fallow	Fallow	0000	17	30	19.67	13.25	575	40.30
1306	Fallow	Fallow	0000	11	30	18.95	15.19	625	14.77
1307	Fallow	Fallow	0000	14	30	21.40	13.75	675	17.12
1308	Milo 3½'	Wheat	4040	1	6	16.52	13.00	475	3.49
1309	Milo 3½'	Fallow	0000	7	14	10.86	10.42	525	9.38
1310	Milo 3½'	Fallow	0000	8	14	18.06	14.87	525	8.53
1311	Milo 3½'	Wheat	2740	5	6	14.25	10.68	875	7.50
1312	Milo 3½'	Wheat	2520	9	6	13.32	16.74	875	4.63
1313	Milo 3½'	Fallow	0000	9	14	15.67	13.28	350	9.61
1314	Milo 3½'	Fallow	0000	9	14	15.52	12.50	375	19.67
1315	Milo 3½'	Fallow	0000	7	14	17.12	15.52	325	15.75
1316	Milo 3½'	Wheat	2290	1	6	13.88	10.22	300	4.81
1317	Milo 3½'	Fallow	0000	4	14	12.71	12.47	525	15.75
1318	Milo 3½'	Fallow	0000	7	14	14.57	13.62	75	22.50
1319	Milo 3½'	Milo 3½'	1570	15	2	10.27	8.24	575	6.30
1320	Milo 3½'	Milo 7'	1045	13	2	13.36	10.85	650	6.73
1321	Milo 3½'	Milo 3½'	975	5	2	10.75	10.56	875	6.40
1322	Milo 3½'	Milo 7'	795	5	2	14.20	14.05	250	13.13
1323	Milo 3½'	Sudan	890	1	2	10.25	7.43	475	.98
1324	Milo 3½'	Sudan	1700	3	2	6.92	6.18	1050	1.56

Table III.—Plot Conditions and Nitrate Nitrogen in Topsoil at Close of Year 1925

Number of Excessive Rains During Year—3.
Months Previous to Nitrate Test in Which 2.95 Inches Effective Rain Fell—3.6

Plot Number	Previous Crop	Crop Grown 1925	Total Yield Lbs. Per Acre	Sum of Cultural Depths Per Year, Inches	Months from Last Harvest to Nitrate Sampling	Percentage of Soil Moisture at Frost 0''-6''	Percentage of Soil Moisture Passing Winter 0''-6''	Raw Organic Matter P. P. M. 0''-6''	Nitrate Nitrogen P. P. M. 0''-6''
1303	Wheat	Wheat	----	11	18	16.66	12.36	825	5.79
1304	Wheat	Fallow	0000	14	18	18.88	12.91	1050	6.96
1305	Fallow	Wheat	----	14	30	16.57	20.10	675	37.41
1306	Fallow	Wheat	----	14	30	16.54	20.72	775	24.96
1307	Fallow	Fallow	0000	13	30	18.25	15.51	600	10.69
1308	Wheat	Fallow	0000	14	18	16.51	20.07	675	24.96
1309	Fallow	Fallow	0000	14	30	15.89	21.55	650	30.01
1310	Fallow	Fallow	0000	15	30	17.68	19.40	450	19.97
1311	Wheat	Wheat	----	12	18	13.50	13.10	975	2.67
1312	Wheat	Fallow	0000	6	18	16.81	13.50	1050	1.41
1313	Fallow	Wheat	----	13	30	16.10	17.00	525	16.64
1314	Fallow	Wheat	----	13	30	13.80	18.12	425	11.63
1315	Fallow	Fallow	0000	7	30	15.68	11.39	250	3.19
1316	Wheat	Fallow	0000	8	18	14.52	16.25	175	9.36
1317	Fallow	Fallow	0000	9	30	15.80	14.21	500	22.39
1318	Fallow	Fallow	0000	15	30	13.55	14.92	100	16.64
1319	Milo 3½'	Milo 3½'	850	20	2	12.08	15.06	975	12.66
1320	Milo 7'	Milo 7'	928	20	2	14.75	15.78	450	6.32
1321	Milo 3½'	Milo 3½'	1610	19	2	11.64	15.37	625	5.12
1322	Milo 7'	Milo 7'	1272	19	2	14.94	13.22	425	5.82
1323	Sudan	Sudan	2124	6	2	13.35	12.60	850	5.16
1324	Sudan	Sudan	1383	14	2	11.68	11.62	1075	2.85

Table IV.—Plot Conditions and Nitrate Nitrogen in Topsoil at Close of Year 1926

Number of Excessive Rains During Year—5.
Months Previous to Nitrate Test in Which 2.95 Inches Effective Rain Fell—6.1.

Plot Number	Previous Crop	Crop Grown 1926	Total Yield Lbs. Per Acre	Sum of Cultural Depths Per Year, Inches	Months from Last Harvest to Nitrate Sampling	Percentage of Soil Moisture at Frost 0''-6''	Percentage of Soil Moisture Passing Winter 0''-6''	Raw Organic Matter P. P. M. 0''-6''	Nitrate Nitrogen P. P. M. 0''-6''
1303	Wheat	Wheat	3750	5	6	14.52	11.33	1225	1.21
1304	Fallow	Wheat	3890	1	6	15.95	18.37	1200	1.91
1305	Wheat	Fallow	0000	8	18	21.63	17.96	650	16.00
1306	Wheat	Fallow	0000	6	18	20.30	19.97	950	12.76
1307	Fallow	Wheat	6290	1	6	17.85	17.58	1225	1.99
1308	Fallow	Fallow	0000	8	30	19.30	19.74	775	21.28
1309	Fallow	Fallow	0000	6	30	13.07	19.77	675	12.07
1310	Fallow	Fallow	0000	6	30	18.21	17.73	525	16.66
1311	Wheat	Wheat	3650	5	6	10.56	9.05	1200	1.45
1312	Fallow	Wheat	4290	1	6	11.52	11.54	1450	1.42
1313	Wheat	Fallow	0000	8	18	15.00	15.31	350	14.57
1314	Wheat	Fallow	0000	12	18	16.43	16.84	500	16.80
1315	Fallow	Wheat	6370	1	6	8.85	8.57	600	1.32
1316	Fallow	Fallow	0000	7	30	14.15	14.81	375	9.84
1317	Fallow	Fallow	0000	6	30	14.67	14.71	525	11.99
1318	Fallow	Fallow	0000	6	30	13.23	14.50	425	21.28
1319	Milo 3½'	Milo 3½'	1083	12	2	11.30	11.59	1000	1.14
1320	Milo 7'	Milo 7'	768	12	2	11.15	14.39	925	9.12
1321	Milo 3½'	Milo 3½'	912	10	2	9.82	11.80	875	1.80
1322	Milo 7'	Milo 7'	732	10	2	10.97	13.44	650	1.88
1323	Sudan	Sudan	2250	3	2	6.10	14.32	725	1.36
1324	Sudan	Sudan	3450	3	2	5.67	6.17	1550	1.36

Table V.—Plot Conditions and Nitrate Nitrogen in Topsoil at Close of Year 1927

Number of Excessive Rains During Year—5.
Months Previous to Nitrate Test in Which 2.95 Inches Effective Rain Fell—4.1.

Plot Number	Previous Crop	Crop Grown 1927	Total Yield Lbs. Per Acre	Sum of Cultural Depths Per Year, Inches	Months from Last Harvest to Nitrate Sampling	Percentage of Soil Moisture at Frost 0"-6"	Percentage of Soil Moisture Passing Winter 0"-6"	Raw Organic Matter P. P. M. 0"-6"	Nitrate Nitrogen P. P. M. 0"-6"
1303	Wheat	Wheat	----	11	18	20.35	17.42	700	15.29
1304	Wheat	Fallow	0000	15	18	23.16	15.90	525	15.29
1305	Fallow	Wheat	----	10	30	24.20	21.45	450	10.42
1306	Fallow	Fallow	0000	11	30	22.33	20.54	450	17.64
1307	Wheat	Fallow	0000	14	18	22.19	21.06	575	14.34
1308	Fallow	Wheat	----	10	30	23.77	18.95	450	12.74
1309	Fallow	Fallow	0000	10	30	22.33	21.31	350	16.39
1310	Fallow	Fallow	0000	10	30	20.76	19.22	175	13.40
1311	Wheat	Wheat	----	11	18	18.74	14.52	1025	8.81
1312	Wheat	Fallow	0000	13	18	18.94	15.00	1200	9.18
1313	Fallow	Wheat	----	12	30	20.07	18.41	500	15.29
1314	Fallow	Fallow	0000	11	30	19.39	15.66	225	7.14
1315	Wheat	Fallow	0000	12	18	18.02	17.13	675	10.42
1316	Fallow	Wheat	----	14	30	17.49	17.44	325	12.04
1317	Fallow	Fallow	0000	10	30	18.20	16.69	150	12.07
1318	Fallow	Fallow	0000	10	30	17.96	17.00	200	11.47
1319	Milo 3½'	Milo 3½'	3378	12	2	10.45	15.89	1025	1.50
1320	Milo 7'	Milo 7'	2457	12	2	11.14	12.16	225	2.49
1321	Milo 3½'	Milo 3½'	2564	12	2	10.84	13.91	550	.90
1322	Milo 7'	Milo 7'	1998	12	2	11.38	13.94	325	1.52
1323	Sudan	Sudan	2380	3	2	13.80	13.43	1250	1.59
1324	Sudan	Sudan	3751	8	2	11.28	11.58	1050	1.59

Table VI.—Plot Conditions and Nitrate Nitrogen in Topsoil at Close of Year 1928

Number of Excessive Rains During Year—8.
Months Previous to Nitrate Test in Which 2.95 Inches Effective Rain Fell—2.3.

Plot Number	Previous Crop	Crop Grown 1928	Total Yield Lbs. Per Acre	Sum of Cultural Depths Per Year, Inches	Months from Last Harvest to Nitrate Sampling	Percentage of Soil Moisture at Frost 0"-6"	Percentage of Soil Moisture Passing Winter 0"-6"	Raw Organic Matter P. P. M. 0"-6"	Nitrate Nitrogen P. P. M. 0"-6"
1303	Wheat	Wheat	5002	3	6	17.23	22.85	625	3.05
1304	Fallow	Wheat	5104	8	6	17.82	22.54	550	4.32
1305	Wheat	Fallow	0000	21	18	24.40	21.78	50	7.17
1306	Fallow	Wheat	7206	18	6	19.17	22.07	275	3.95
1307	Fallow	Fallow	0000	15	30	23.98	21.78	475	8.50
1308	Wheat	Fallow	0000	18	18	24.29	21.86	150	13.50
1309	Fallow	Fallow	0000	14	30	20.48	22.13	225	8.19
1310	Fallow	Fallow	0000	14	30	22.40	21.20	200	3.95
1311	Wheat	Wheat	4859	8	6	14.47	20.79	1025	1.81
1312	Fallow	Wheat	4494	4	6	18.08	20.60	1150	2.66
1313	Wheat	Fallow	0000	19	18	19.90	18.73	300	2.29
1314	Fallow	Wheat	5173	4	6	15.31	20.57	550	3.31
1315	Fallow	Fallow	0000	22	30	22.24	15.64	250	6.19
1316	Wheat	Fallow	0000	16	18	19.88	15.58	750	5.21
1317	Fallow	Fallow	0000	12	30	22.10	21.81	125	7.17
1318	Fallow	Fallow	0000	10	30	21.17	19.10	325	2.54
1319	Milo 3½'	Milo 3½'	2608	22	2	13.38	16.76	550	3.05
1320	Milo 7'	Milo 7'	2054	22	2	20.65	18.53	150	4.77
1321	Milo 3½'	Milo 3½'	1265	13	2	12.33	21.55	625	4.59
1322	Milo 7'	Milo 7'	1302	13	2	16.87	21.96	225	9.86
1323	Sudan	Sudan	2210	1	2	13.10	17.91	700	1.65
1324	Sudan	Sudan	2733	8	2	11.22	18.87	950	1.70

Table VII.—Plot Conditions and Nitrate Nitrogen in Topsoil at Close of Year 1929

Number of Excessive Rains During Year—6.
Months Previous to Nitrate Test in Which 2.95 Inches Effective Rain Fell—3.5.

Plot Number	Previous Crop	Crop Grown 1929	Total Yield Lbs. Per Acre	Sum of Cultural Depths Per Year, Inches	Months from Last Harvest to Nitrate Sampling	Percentage of Soil Moisture at Frost 0''-6''	Percentage of Soil Moisture Passing Winter 0''-6''	Raw Organic Matter P. P. M. 0''-6''	Nitrate Nitrogen P. P. M. 0''-6''
1303	Wheat	Wheat	1500	9	6	16.36	21.00	1050	14.36
1304	Wheat	Fallow	0000	15	18	20.40	24.04	400	17.90
1305	Fallow	Wheat	4150	12	6	16.58	23.20	450	1.31
1306	Wheat	Fallow	0000	14	18	16.39	24.47	525	13.05
1307	Fallow	Wheat	4150	4	6	14.94	20.50	350	2.61
1308	Fallow	Fallow	0000	13	30	17.77	21.74	200	13.05
1309	Fallow	Fallow	0000	10	30	21.36	21.38	275	10.25
1310	Fallow	Fallow	0000	10	30	21.34	20.57	375	11.04
1311	Wheat	Wheat	1280	9	6	15.15	18.16	1025	1.71
1312	Wheat	Fallow	0000	12	18	18.75	16.02	1200	7.17
1313	Fallow	Wheat	4500	7	6	14.00	16.41	575	1.71
1314	Wheat	Fallow	0000	12	18	16.98	17.72	300	7.96
1315	Fallow	Wheat	4300	9	6	14.82	18.95	400	1.61
1316	Fallow	Fallow	0000	13	30	18.80	15.49	225	6.00
1317	Fallow	Fallow	0000	10	30	19.57	18.63	75	5.98
1318	Fallow	Fallow	0000	12	30	20.16	19.29	125	6.24
1319	Milo 3½'	Milo 3½'	1340	19	2	12.75	19.81	800	.81
1320	Milo 7'	Milo 7'	1650	19	2	13.72	19.38	150	2.68
1321	Milo 3½'	Milo 3½'	1740	13	2	13.78	20.78	425	1.21
1322	Milo 7'	Milo 7'	1480	13	2	16.82	19.49	400	1.74
1323	Sudan	Sudan	1339	4	2	11.32	18.07	800	.66
1324	Sudan	Sudan	1580	8	2	11.41	15.90	1275	1.21

Table VIII.—Plot Conditions and Nitrate Nitrogen in Topsoil at Close of Year 1930

Number of Excessive Rains During Year—5.
Months Previous to Nitrate Test in Which 2.95 Inches Effective Rain Fell—2.6.

Plot Number	Previous Crop	Crop Grown 1930	Total Yield Lbs. Per Acre	Sum of Cultural Depths Per Year, Inches	Months from Last Harvest to Nitrate Sampling	Percentage of Soil Moisture at Frost 0''-6''	Percentage of Soil Moisture Passing Winter 0''-6''	Raw Organic Matter P. P. M. 0''-6''	Nitrate Nitrogen P. P. M. 0''-6''
1303	Wheat	Wheat	----	8	6	22.23	15.72	1425	5.89
1304	Fallow	Wheat	450	6	6	25.04	17.30	950	13.73
1305	Wheat	Fallow	0000	10	18	21.46	17.13	1025	13.73
1306	Fallow	Fallow	0000	9	30	25.41	16.07	1050	4.12
1307	Wheat	Fallow	0000	14	18	24.05	23.61	1000	14.71
1308	Fallow	Wheat	2710	6	6	22.95	18.48	650	4.64
1309	Fallow	Fallow	0000	10	30	22.64	18.00	250	7.92
1310	Fallow	Fallow	0000	10	30	23.17	19.61	575	10.30
1311	Wheat	Wheat	----	9	6	22.57	17.35	1275	2.48
1312	Fallow	Wheat	1650	10	6	20.83	24.55	1425	6.44
1313	Wheat	Fallow	0000	2	18	17.49	12.10	1100	4.64
1314	Fallow	Fallow	0000	9	30	20.40	13.64	1050	2.71
1315	Wheat	Fallow	0000	6	18	20.55	17.81	750	5.77
1316	Fallow	Wheat	2870	10	6	20.23	19.63	225	1.91
1317	Fallow	Fallow	0000	8	30	19.77	23.67	275	4.12
1318	Fallow	Fallow	0000	8	30	21.87	15.73	250	4.12
1319	Milo 3½'	Milo 3½'	2860	14	2	19.74	14.93	575	1.19
1320	Milo 7'	Milo 7'	1770	14	2	19.91	20.36	275	1.54
1321	Milo 3½'	Milo 3½'	1840	11	2	21.65	19.50	275	1.26
1322	Milo 7'	Milo 7'	1760	11	2	26.83	20.18	125	1.41
1323	Sudan	Sudan	1622	2	2	19.64	17.76	1075	1.35
1324	Sudan	Sudan	1798	8	2	20.93	16.41	1750	1.11

Table IX.—Plot Conditions and Nitrate Nitrogen in Topsoil at Close of Year 1926, Rotation Series 1100

Plot Number	Previous Crop	Crop Grown 1926	Total Yield Lbs. Per Acre	Sum of Cultural Depths Per Year, Inches	Months from Last Harvest to Nitrate Sampling	Nitrate Nitrogen P. P. M. 0"-6"
1101	Milo 3½'	Fallow	0000	7	14	22.85
1102	Fallow	Wheat	6730	9	6	2.13
1103	Wheat	Milo 3½'	2100	12	2	14.54
1104	Wheat	Fallow	0000	10	18	21.33
1105	Fallow	Milo 7'	1534	9	2	2.96
1106	Milo 7'	Wheat	3770	7	6	2.80
1107	Milo 7'	Fallow	0000	20	14	22.85
1108	Fallow	Cowpeas	1510	12	3	14.54
1109	Cowpeas	Milo 7'	1368	10	2	13.91
1110	Oats	Wheat	6040	0	6	4.43
1111	Wheat	Kafir 7'	760	8	2	8.19
1112	Kafir 7'	Oats	2640	6	6	1.60
1113	Oats	Fallow	0000	7	18	9.42
1114	Fallow	Wheat	5150	3	6	1.27
1115	Wheat	Oats	3600	4	6	2.96
1116	Corn	Oats	2710	4	6	8.53
1117	Oats	Fallow	0000	8	18	11.42
1118	Fallow	Wheat	5380	3	6	1.28
1119	Wheat	Corn 7'	1258	4	4	4.67
1120	Alfalfa	Alfalfa	822	0	0	4.32
1121	Wheat	Weed Manure	0000	10	7	6.18
1122	Fallow	Milo 3½'	1040	10	2	5.96
1123	Milo 3½'	Cowpeas	1492	12	3	1.32
1124	Cowpeas	Wheat	4940	4	6	1.62

Table X.—Plot Conditions and Nitrate Nitrogen in Topsoil at Close of Year 1927, Rotation Series 1100

Plot Number	Previous Crop	Crop Grown 1927	Total Yield Lbs. Per Acre	Sum of Cultural Depths Per Year, Inches	Months from Last Harvest to Nitrate Sampling	Nitrate Nitrogen P. P. M. 0"-6"
1101	Fallow	Wheat	----	9	6	11.47
1102	Wheat	Milo 3½'	2440	15	2	1.84
1103	Milo 3½'	Fallow	0000	11	14	7.17
1104	Fallow	Fallow	0000	9	30	8.47
1105	Milo 7'	Wheat	----	8	6	10.42
1106	Wheat	Fallow	0000	10	18	12.74
1107	Fallow	Cowpeas	700	14	3	12.07
1108	Cowpeas	Milo 7'	1550	14	2	8.19
1109	Milo 7'	Fallow	0000	10	14	11.47
1110	Wheat	Kafir 7'	650	8	2	5.21
1111	Kafir 7'	Oats	----	17	6	9.34
1112	Oats	Wheat	----	8	6	13.44
1113	Fallow	Wheat	----	9	6	9.55
1114	Wheat	Oats	----	14	6	12.74
1115	Oats	Fallow	0000	17	18	16.39
1116	Oats	Fallow	0000	17	18	14.34
1117	Fallow	Wheat	----	9	6	12.74
1118	Wheat	Corn 7'	109	18	4	14.34
1119	Corn	Oats	----	8	6	7.70
1120	Alfalfa	Alfalfa	----	0	0	1.86
1121	Fallow	Milo 3½'	1120	13	2	2.79
1122	Milo 3½'	Cowpeas	688	10	3	6.03
1123	Cowpeas	Wheat	----	12	6	9.55
1124	Wheat	Fallow	0000	6	18	19.11

Table XI.—Plot Conditions and Nitrate Nitrogen in Topsoil at Close of Year 1928, Rotation Series 1100

Plot Number	Previous Crop	Crop Grown 1928	Total Yield Lbs. Per Acre	Sum of Cultural Depths Per Year, Inches	Months from Last Harvest to Nitrate Sampling	Nitrate Nitrogen P. P. M. 0"-6"
1101	Wheat	Milo 3½'	1775	22	2	6.28
1102	Milo 3½'	Fallow	0000	13	14	10.29
1103	Fallow	Wheat	5350	3	6	3.89
1104	Fallow	Wheat	5600	7	6	7.54
1105	Wheat	Fallow	0000	14	18	11.32
1106	Fallow	Milo 7'	1755	17	2	7.80
1107	Cowpeas	Milo 7'	1796	22	2	11.32
1108	Milo 7'	Fallow	0000	21	14	11.32
1109	Fallow	Cowpeas	1409	12	3	5.38
1110	Kafir 7'	Oats	1330	12	6	3.40
1111	Oats	Wheat	4905	9	6	5.66
1112	Wheat	Kafir 7'	1544	16	2	8.70
1113	Wheat	Oats	4831	15	6	4.71
1114	Oats	Fallow	0000	19	18	14.15
1115	Fallow	Wheat	5680	9	6	4.04
1116	Fallow	Wheat	4920	9	6	5.14
1117	Wheat	Corn 7'	796	16	4	4.91
1118	Corn 7'	Oats	4401	7	6	2.40
1119	Oats	Fallow	0000	12	18	16.18
1120	Alfalfa	Alfalfa	0000	17	14	25.17
1121	Milo 3½'	Cowpeas	2629	11	3	7.07
1122	Cowpeas	Barley	4520	10	6	3.05
1123	Wheat	Fallow	0000	14	18	14.15
1124	Fallow	Milo 3½'	1514	10	2	3.05

Table XII.—Plot Conditions and Nitrate Nitrogen in Topsoil at Close of Year 1929, Rotation Series 1100

Plot Number	Previous Crop	Crop Grown 1929	Total Yield Lbs. Per Acre	Sum of Cultural Depths Per Year, Inches	Months from Last Harvest to Nitrate Sampling	Nitrate Nitrogen P. P. M. 0"-6"
1101	Milo 3½'	Fallow	0000	12	14	6.60
1102	Fallow	Wheat	4080	5	6	1.76
1103	Wheat	Milo 3½'	1748	23	2	4.30
1104	Wheat	Fallow	0000	13	18	7.61
1105	Fallow	Milo 7'	1902	16	2	3.52
1106	Milo 7'	Wheat	3450	9	6	2.36
1107	Milo 7'	Fallow	0000	11	14	18.20
1108	Fallow	Cowpeas	994	13	3	10.10
1109	Cowpeas	Milo 7'	1522	13	2	3.95
1110	Oats	Wheat	500	5	6	1.23
1111	Wheat	Kafir 7'	503	10	2	7.56
1112	Kafir 7'	Oats	855	13	6	1.28
1113	Oats	Fallow	0000	12	18	6.98
1114	Fallow	Wheat	4250	5	6	3.03
1115	Wheat	Oats	730	6	6	2.92
1116	Wheat	Corn 7'	476	15	4	1.94
1117	Corn 7'	Oats	1830	6	6	3.05
1118	Oats	Fallow	0000	13	18	9.57
1119	Fallow	Alfalfa	0000	1	0	.66
1120	Alfalfa	Wheat	4340	5	6	2.24
1121	Cowpeas	Wheat	2900	5	6	3.12
1122	Barley	Fallow	0000	14	18	11.10
1123	Fallow	Milo 3½'	2862	10	2	1.75
1124	Milo 3½'	Cowpeas	1229	14	3	5.50

Table XIII.—Plot Conditions and Nitrate Nitrogen in Topsoil at Close of Year 1930, Rotation Series 1100

Plot Number	Previous Crop	Crop Grown 1930	Total Yield Lbs. Per Acre	Sum of Cultural Depths Per Year, Inches	Months from Last Harvest to Nitrate Sampling	Nitrate Nitrogen P. P. M. 0"-6"
1101	Fallow	Wheat	----	13	6	5.06
1102	Wheat	Milo 3½'	1483	20	2	1.41
1103	Milo 3½'	Fallow	0000	14	14	2.12
1104	Fallow	Milo 7'	1684	17	2	7.27
1105	Milo 7'	Wheat	700	10	6	1.99
1106	Wheat	Fallow	0000	9	18	9.07
1107	Fallow	Beans	7876	14	2	3.99
1108	Beans	Milo 7'	1764	16	2	5.13
1109	Milo 7'	Fallow	0000	11	14	7.67
1110	Wheat	Milo 7'	2843	19	2	4.89
1111	Kafir 7'	Barley	----	20	6	2.37
1112	Oats	Wheat	270	13	6	6.93
1113	Fallow	Wheat	290	7	6	4.38
1114	Wheat	Barley	----	18	6	6.93
1115	Oats	Fallow	0000	13	18	2.87
1116	Corn	Barley	260	12	6	3.61
1117	Oats	Fallow	0000	11	18	2.08
1118	Fallow	Wheat	920	13	6	4.62
1119	Alfalfa	Alfalfa	334	0	0	.94
1120	Wheat	Corn	430	21	4	4.16
1121	Wheat	Fallow	0000	10	18	6.93
1122	Fallow	Milo 3½'	1896	12	2	2.45
1123	Milo	Beans	4963	16	2	2.97
1124	Beans	Wheat	650	8	6	3.78

Table XIV.—Plot Conditions and Nitrate Nitrogen in Topsoil at Close of Year 1926, Rotation Series 1200

Plot Number	Previous Crop	Crop Grown 1926	Total Yield Lbs. Per Acre	Sum of Cultural Depths Per Year, Inches	Months from Last Harvest to Nitrate Sampling	Nitrate Nitrogen P. P. M. 0"-6"
1201	Milo 7'	Cowpeas	1375	14	3	11.02
1202	Cowpeas	Wheat	4640	3	6	1.88
1203	Wheat	Milo 7'	1066	18	2	7.61
1204	Wheat	Fallow	0000	10	18	16.83
1205	Fallow	Corn 3½'	1775	7	4	8.00
1206	Corn	Wheat	7280	3	6	4.57
1207	Milo 7'	Wheat	3820	3	6	6.15
1208	Wheat	Cowpeas	985	13	3	11.84
1209	Cowpeas	Milo 7'	1038	12	2	11.42
1210	Oats	Cowpeas	1181	20	3	11.84
1211	Cowpeas	Kafir 3½'	208	7	2	4.70
1212	Kafir 3½'	Oats	2910	4	6	1.07
1213	Sudan	Fallow	0000	11	14	14.54
1214	Fallow	Corn 7'	1022	6	4	6.40
1215	Corn	Sudan	5300	3	2	3.13
1216	Swt. Clo.	Swt. Clover	0000	1	2	4.85
1217	Swt. Clo.	Corn 7'	567	4	4	7.27
1218	Corn 7'	Swt. Clover	0000	1	0	6.09
1219	Alfalfa	Milo 7'	582	8	2	12.30
1220	Alfalfa	Milo 7'	664	8	2	13.33
1221	Fallow	Milo 3½'	856	12	2	8.88
1222	Milo 3½'	Cowpeas	1263	10	3	8.88
1223	Cowpeas	Wheat	3250	3	6	2.21
1224	Wheat	Fallow	0000	10	18	13.33

Table XV.—Plot Conditions and Nitrate Nitrogen in Topsoil at Close of Year 1927, Rotation Series 1200

Plot Number	Previous Crop	Crop Grown 1927	Total Yield Lbs. Per Acre	Sum of Cultural Depths Per Year, Inches	Months from Last Harvest to Nitrate Sampling	Nitrate Nitrogen P. P. M. 0"-6"
1201	Cowpeas	Wheat	----	8	6	14.34
1202	Wheat	Milo 7'	965	21	2	3.81
1203	Milo 7'	Cowpeas	511	11	3	7.17
1204	Fallow	Corn 3½'	697	15	4	8.19
1205	Corn 3½'	Wheat	----	8	6	9.97
1206	Wheat	Fallow	0000	14	18	5.21
1207	Wheat	Cowpeas	584	20	3	12.74
1208	Cowpeas	Milo 7'	2655	12	2	3.47
1209	Milo 7'	Wheat	----	8	6	22.95
1210	Cowpeas	Kafir 3½'	2755	12	2	2.79
1211	Kafir 3½'	Oats	----	8	6	16.39
1212	Oats	Cowpeas	533	21	3	16.39
1213	Fallow	Corn 7'	272	16	4	8.47
1214	Corn 7'	Sudan	6206	4	2	1.61
1215	Sudan	Fallow	0000	16	14	6.36
1216	Swt. Clo.	Corn 7'	125	23	4	9.11
1217	Corn 7'	Swt. Clover	0000	8	0	14.34
1218	Swt. Clo.	Swt. Clover	0000	8	2	11.47
1219	Milo 7'	Fallow	0000	11	14	7.70
1220	Milo 7'	Milo 7'	810	11	2	2.55
1221	Milo 3½'	Cowpeas	482	14	3	9.11
1222	Cowpeas	Wheat	----	9	6	8.81
1223	Wheat	Fallow	0000	16	18	17.64
1224	Fallow	Milo 3½'	----	18	2	2.20

Table XVI.—Plot Conditions and Nitrate Nitrogen in Topsoil at Close of Year 1928, Rotation Series 1200

Plot Number	Previous Crop	Crop Grown 1928	Total Yield Lbs. Per Acre	Sum of Cultural Depths Per Year, Inches	Months from Last Harvest to Nitrate Sampling	Nitrate Nitrogen P. P. M. 0"-6"
1201	Wheat	Milo 7'	1940	18	2	3.64
1202	Milo 7'	Cowpeas	2277	14	3	3.05
1203	Cowpeas	Barley	5430	4	6	3.53
1204	Corn 3½'	Wheat	4775	4	6	4.71
1205	Wheat	Fallow	0000	16	18	6.46
1206	Fallow	Corn 3½'	1777	17	4	2.93
1207	Cowpeas	Milo 7'	1115	13	2	3.05
1208	Milo 7'	Wheat	1705	4	6	5.66
1209	Wheat	Cowpeas	2481	18	3	3.53
1210	Kafir 3½'	Oats	2925	14	6	2.57
1211	Oats	Cowpeas	2308	22	3	3.32
1212	Cowpeas	Kafir 3½'	743	12	2	3.23
1213	Corn 7'	Sudan	1744	7	2	3.23
1214	Sudan	Fallow	0000	20	14	6.28
1215	Fallow	Corn 7'	808	10	4	2.40
1216	Corn 7'	Swt. Clover	0000	8	0	4.53
1217	Swt. Clo.	Swt. Clover	0000	8	2	10.29
1218	Swt. Clo.	Corn 7'	984	16	4	4.04
1219	Fallow	Wheat	4940	7	6	2.26
1220	Milo 7'	Milo 3½'	660	16	2	2.45
1221	Cowpeas	Barley	5640	10	6	2.75
1222	Wheat	Fallow	0000	23	18	5.38
1223	Fallow	Milo 3½'	1787	14	2	3.23
1224	Milo 3½'	Cowpeas	2298	18	3	2.89

Table XVII.—Plot Conditions and Nitrate Nitrogen in Topsoil at Close of Year 1929, Rotation Series 1200

Plot Number	Previous Crop	Crop Grown 1929	Total Yield Lbs. Per Acre	Sum of Cultural Depths Per Year, Inches	Months from Last Harvest to Nitrate Sampling	Nitrate Nitrogen P. P. M. 0'-6"
1201	Milo 7'	Cowpeas	1008	21	3	5.52
1202	Cowpeas	Wheat	1880	5	6	1.85
1203	Barley	Milo 7'	636	16	2	9.57
1204	Wheat	Fallow	0000	22	18	15.95
1205	Fallow	Corn 3½'	568	15	4	1.89
1206	Corn 3½'	Wheat	3340	5	6	2.35
1207	Milo 7'	Wheat	2140	5	6	2.61
1208	Wheat	Cowpeas	753	19	3	13.71
1209	Cowpeas	Milo 7'	2014	14	2	4.80
1210	Oats	Cowpeas	688	13	3	7.54
1211	Cowpeas	Kafir 3½'	2067	15	2	2.11
1212	Kafir 3½'	Oats	1460	9	6	1.79
1213	Sudan	Fallow	0000	17	14	11.00
1214	Fallow	Corn 7'	528	14	4	2.20
1215	Corn 7'	Sudan	882	2	2	1.61
1216	Swt. Clo.	Swt. Clover	0000	0	0	1.34
1217	Swt. Clo.	Corn 7'	297	15	4	10.15
1218	Corn 7'	Swt. Clover	0000	2	0	1.76
1219	Wheat	Wheat	1110	5	6	2.93
1220	Milo 3½'	Wheat	1850	5	6	3.88
1221	Barley	Fallow	0000	8	18	7.33
1222	Fallow	Milo 3½'	2017	18	2	1.14
1223	Milo 3½'	Cowpeas	913	13	3	3.67
1224	Cowpeas	Wheat	3480	5	6	4.00

Table XVIII.—Plot Conditions and Nitrate Nitrogen in Topsoil at Close of Year 1930, Rotation Series 1200

Plot Number	Previous Crop	Crop Grown 1930	Total Yield Lbs. Per Acre	Sum of Cultural Depths Per Year, Inches	Months from Last Harvest to Nitrate Sampling	Nitrate Nitrogen P. P. M 0"-6"
1201	Beans	Wheat	220	12	6	7.07
1202	Wheat	Milo 7'	1020	14	2	7.07
1203	Milo	Beans	4832	15	2	3.93
1204	Fallow	Corn 3½'	280	15	4	12.85
1205	Corn 3½'	Wheat	...	10	6	10.87
1206	Wheat	Fallow	0000	18	18	11.77
1207	Wheat	Beans	3758	20	2	3.21
1208	Beans	Milo 7'	1312	15	2	7.85
1209	Milo 7'	Wheat	......	11	6	3.82
1210	Beans	Kafir 3½'	2477	12	2	4.56
1211	Kafir 3½'	Barley	......	15	6	5.65
1212	Oats	Beans	4315	22	2	4.04
1213	Fallow	Corn 7'	640	14	4	15.68
1214	Corn 7'	Sudan	5980	10	2	.94
1215	Sudan	Fallow	0000	18	14	11.63
1216	Swt. Clo.	Corn 7'	510	22	4	14.54
1217	Corn 7'	Swt. Clover	0000	2	0	3.14
1218	Swt. Clo.	Swt. Clover	0000	6	0	6.09
1219	Wheat	Milo	1204	13	2	7.84
1220	Wheat	Fallow	0000	9	18	1.46
1221	Fallow	Milo 3½'	1331	15	2	3.64
1222	Milo 3½'	Beans	3822	13	2	2.53
1223	Beans	Wheat	230	11	6	7.76
1224	Wheat	Fallow	0000	16	18	11.75

Table XIX.—Summary of Significant Climatic Features

YEAR	No. of Rains of 1.00 Inch Plus the Previous Year	No. Months Previous to Sampling Giving 2.95 Inches Effective Rain
1923	7	2.3
1924	3	5.5
1925	3	3.6
1926	5	6.1
1927	5	4.1
1928	8	2.3
1929	6	3.5
1930	5	2.6

PART I

FACTORS AFFECTING TOPSOIL NITRATE ACCUMULATION IN SINGLE CROPPING SYSTEMS

The Character of Variables Studied

On account of the fact that soil moisture data are lacking for the rotation series 1100 and 1200 these data have been divided into two groups for general statistical analyses. The moisture study series 1300, consisting of 22 plots, affords data on six independent variables for a period of eight years totaling 164 plot-year observations. In the analysis of this material it will be designated as Group A. Table XX shows the mean, deviation and variability for each of the factors of the group.

The variation shown in the crop yields removed from this group of plots will be noted to be considerably higher than from the rotation group (B). The reason for this is the abnormal cropping system applied on series 1300 for the purpose of obtaining variables primarily adapted to soil moisture investigations.

The variation in intensity of tillage is greater in this experiment than would be found under usual farm conditions, the extreme ranging from no cultivation for a one-year period up to as high as a total of 22 inches for the year.

The time interval between harvest and sampling is also somewhat exaggerated in this particular experiment, the average for all plots being 12.8 months. This is practically equivalent to straight alternate cropping and not considered representative of the best crop sequence. However, it serves as well in determining the relation of factors controlling nitrates, perhaps, as those controlling soil moisture.

Mean topsoil moisture content at frost in the fall for this group of plots was 16.86 per cent. This is but .26 more than was found four months later and corresponds almost exactly with the small tendency to moisture changes observed in previous studies (8), where observations covered dry to moderately dry periods of the year. The extent of variability in this case, where topsoil moisture alone was being considered, is shown to be somewhat greater than in previous studies (8) where the entire 6-foot soil section was involved. The apparent trend to a slight reduction in differences between topsoil moisture among the plots of this series as the fall and winter progresses is apparently due in part to the cropping schedule whereby winter wheat was introduced on six plots, four of which had been prepared by fallowing. The insignificant difference between the mean moisture content at frost and at midwinter, however, indicates that compensating gains, though small ones, had been obtained on the unoccupied plots.

Table XX.—Classes of Group A

Variable	No. of Obser- vations	Mean of Class	Standard Deviation	Coefficient of Varia- bility
Y—Total Yield	164	1229±.82	1579	128.3
S—Cultivation	164	10.63±.26	5.04	47.4
I—Interval Between Last Previous Harvest and Nitrate Sampling	164	12.80±.59	11.28	88.1
B—Topsoil Moisture at Frost	164	16.86±.21	4.13	24.4
J—Topsoil Moisture Content Passing the Winter	164	16.60±.18	3.51	21.1
O—Raw Organic Matter Content of Topsoil	164	652±.17	334	51.2
R—Earliness of Effective Rains	8(22)	3.82±1.4	6.11	159.9
G—No. Excessive Rains Previous Year	8(22)	5.17±1.7	7.40	143.1
N—Nitrate Nitrogen	164	8.06±.40	7.74	96.0

Table XXI.—Correlation of Factors Relating to Nitrate Nitrogen Accumulation Group A, 1924-30

					(n164)					
	Y	S	I	B	J	O	R	G	N	Beta—N
Y	1.0000	–.3410	–.5981	–.3465	–.0546	.1818	.0446	.1822	–.5102	–.0341
S		1.0000	.1048	.3235	.3335	–.2476	–.4504	.2635	.1732	.1903
I			1.0000	.4166	.1979	–.2513	.0307	–.1061	.7031	.4718
B				1.0000	.6188	–.1317	–.4953	.3432	.3737	.2002
J					1.0000	–.2230	–.5723	.5618	.2078	.3121
O						1.0000	.1062	–.0969	–.2030	–.0050
R							1.0000	–.6098	.2078	.3640
G								1.0000	–.3033	–.3200
Multiple Correlation Rojgbisyn										.8340

Relation of Factors in Group A

While it must be kept in mind that the cropping system and cultural practice included extreme measures in this group of plots, not representative of ordinary farm practice, the relations of certain factors to nitrate accumulation remain important even in their less exaggerated expression. All of the factors except two included in the regression equation, Betas of which are shown in Table XXI along with the simple and multiple correlations, gave evidence of significant independent relationship to nitrate accumulation. Of the factors showing positive correlation, I, the time interval was of greatest importance, rIN being .7031 and Beta in .4718. It appears that though the time for fertility recovery be extended to as long as 30 months, as it was in many cases of this group of plots, the quickening of nitrate formation continues.

It seems quite probable that the continued acceleration of nitrification for this period of time after the last crop was removed is in part due to the reduction of the nitrogen-carbon ratio. It was very noticeable that, when fallowing was continued beyond three years, the raw organic matter content fell to a minimum and nitrate accumulations in the topsoil began to be consistently lower than on plots similarly treated but more recently cropped. Four of the plots of this series were continuously fallowed for from six to eight years. Because of the abnormal handling of these plots they were eliminated from the calculation during the last three years of the experiment. (See Part IV.)

The fact that the time interval operates to the advantage of nitrification a period of approximately three years gives some indication of the normal rate of decomposition of organic matter in the heavy silt loam soils of the southwestern High Plains area.

Next in importance as to the bearing upon nitrate accumulation was the distribution of effective rainfall with special reference to the fall and early winter season. This factor, R, the number of days next preceding the date of nitrate sampling in which 2.95 inches of effective rain fell, has a simple correlation with nitrate stores of .2078, the regression coefficient being (Beta rn) .3640. Although, as has been previously noted (8), leaching with reference to the six-foot soil section appears to be slow, the displacement of solubles from the surface six inches occurs quite frequently.

In this connection a second time interval was introduced whereby is shown the importance of time not only for the recovery of fertility condition following soil exhaustion by crop growth but also following complete or partial exhaustion of the surface layer of nitrates by leaching into the sub-surface or subsoil. Obviously the longer the period endured next preceding the nitrate determination without enough effective rainfall to displace the surface soil moisture, the greater was the opportunity for building up a surface soil store of nitrates.

Of nearly equal significance to the distribution of rainfall was the number of excessive rains during the previous year without regard to the time they fell. The correlations were rGN -.3033, Beta gn -.3200. However, it should be noted that the majority of effective rains came within the crop growing seasons of the year, in other words, during the period April to October inclusive. Both the distribution and number were quite varied as will be seen by a reference to Table XIX. It might be thought at first glance that a correlation with the total amount of rainfall during the year would be of greater value but this is markedly contrary to the facts in this case. As with the effectiveness of rainfall relative to the soil and water relations (8), it is the character of the rainfall, rather than amount within the normal variations, that is of greatest importance. It should be remembered that the nitrate content of the topsoil observed during the dormant period of the year is no indication whatever of the amount of nitrates formed during the previous year, but is merely a measure of the amount being formed in this area (0"-6") which has escaped conversion (into organic residues), removal (in crops harvested) and displacement (to subsurface and subsoil). The number of leachings to which the growing supply of nitrates is subjected during the year is consequently of importance regardless of their timing, particularly in view of the fact that a complete leaching even of the upper six inches can not be too frequently expected.

Of some direct relation to the distribution and character of the rainfall are, of course, the topsoil moisture contents at different times of the year. Since soil moisture is largely affected by crop growth and by tillage as well, and since nitrification has certain soil moisture requirements for optimum progress, these factors assume some importance independent of the simple transportation of nitrates that have been formed. The continuation of favorable conditions for nitrification through the fall of the year, as indicated by the presence of adequate topsoil moisture, is of positive significance in relation to the topsoil nitrate accumulation; because it affords an opportunity for replenishing the nitrate store at a time following which it is least apt to be disposed of either by conversion, removal or displacement. The simple correlation rBN was .3737 and Beta bn, .2002.

Although there is very little doubt that nitrification is more rapid during the fall than in the dead of winter, the importance of topsoil moisture content which passes the winter season appears to be the greater. The correlations are rJN .2078 and Beta jn .3121. The simple correlation between B and J, soil moisture content in the fall and winter respectively, is low enough (.1688) to suggest that factors other than climatic, adding to and taking from the moisture of all plots more or less alike, have been active. As brought out in discussing the derivation of factors I and J, the significance of the persistence of a topsoil moisture supply through the winter probably attaches more to the introduction of winter grains upon some of the plots than to any other one thing. Admitting that some nitrification undoubtedly goes on during the warmer weather of a broken winter (and possibly even more than is usually suspected during cold weather), the action of the young growing crop in removing both stored nitrates and moisture would remain a primary factor in determining favorable conditions for bacterial activity in-so-much as this is the normally dry season of the year.

In departing from the consideration of moisture factors there may be seen, in the interrelation of cultural intensity, the indications of a normal relation with a number of determining conditions. The highest yield removals being customarily taken from broadcast rather than cultivated crops, there appears the correlation rSY -.3410. Little if any relation exists between the intensity of culture and the time the land is vacant, rSI being .1048. Consistent relations are shown between the intensity of culture and topsoil moisture content both in the fall and winter. The rSB equals .3235 and rSJ .3335. Whether the increased topsoil moisture content was due to the previous culture, or the increased culture was required by the presence of excessive moisture to control weeds, may be left to the imagination of the reader. The latter interpretation is suggested by the slightly larger relation shown between the amount of tillage given and the earliness of effective rains. The rSR was -.4504, indicating that a continuation of effective rainfall through toward the end of the year necessitated a greater amount of tillage.

The other relations of S, intensity of culture, are small, but consistent with the observations generally recognized. Increased tillage was associated with the larger number of excessive rains, rSG .2635. The relation between the previous year's tillage and the raw organic matter present was negative, rSO being -.2476, and that between previous tillage and nitrate accumulation was positive, rSN being .1732. The latter correlation, though small, was substantiated by the regression equation. Beta sn was .1903.

There remain for discussion two factors which are related in the sense of their bearings upon the fertility resources of the soil. The crop removals during the previous year show a substantial simple negative correlation with nitrate accumulations rYN being -.5102, but from the regression equation it would seem to have no independent significance. Beta yn was -.0341. The same thing is to a lesser extent true of the presence of raw organic matter as related to nitrate where rON equaled -.2030 and Beta on was -.0050. Large yield removals were naturally negatively associated with intensity of culture, rest period, and topsoil moisture at frost, all of which were independently related to nitrate accumulation. The same was true with the presence of raw organic matter, cultural intensity, rest period, and topsoil moisture content during the winter. These relations almost entirely eliminated the importance of yield removals and the presence of raw organic matter in the regression equations.

The multiple correlation Rojglisyn of .8340 leaves undiscovered some factor or factors approximating .5520, r and Beta. Only one factor included in this study exceeds this value, so it is apparent that there are other important conditions affecting the nitrate residues in the topsoil which are not accounted for in this analysis. Were the topsoil nitrate content of the soil estimated on the basis of the eight factors calculated, the error of estimate would be 4.27 parts per million, which is 55 per cent of the standard deviation (see Table XX). The principal interest of the above analyses lies in the relative importance of the various factors associated with the nitrate accumulation. These factors may be listed in the following order based upon the percentage of the total known influence or association:

I—Interval of rest	24.86
R—Earliness of effective rain	19.18
G—Number of excessive rains	-16.86
J—Topsoil moisture content during winter	16.44
B—Topsoil moisture content at frost	10.55
S—Cultivation	10.02
Y—Total yield removed	-1.79
O—Raw organic matter present	-.26

PART II

TOPSOIL NITRATE ACCUMULATION AS AFFECTED BY CROP ROTATION

Character of Variables Studied

The data available on the soils of rotation experiments date from 1926 to 1930 inclusive, and include the observation of three plot factors in addition to nitrate nitrogen content of the topsoil on 48 plots annually. The total number of observations in this group is 240. For comparative purposes, data for the period 1926-30 of the moisture study, series 1300, are separated from the main group giving 98 observations.

In Table XXII will be found the means and variability of the factors used in this particular analysis. The means and variability during the last five years of the moisture study series, and the entire eight years of the moisture study series (see Table XX), do not vary a great deal in respect to cultivation and rest interval; but it will be noted that the yields removed from the plots averaged higher during the latter part of the period by approximately 260 pounds per acre, and the nitrate nitrogen averaged lower by approximately 1.9 parts per million.

Comparing the two experiments during the period 1926-30, there was little difference in the average yields removed and nitrates accumulated; but the plots in rotation received somewhat more cultivation and only about half the average interval of rest given by the cropping systems used on series 1300. There was 37.8% of the land area summer fallowed each year in the moisture study experiment, and only 20% in the rotation experiment. The extremes of cropping schedule in the moisture study experiment were accompanied by what may possibly be a significantly higher coefficient of variability of nitrates than was observed among the rotation plots.

Table XXII.—Classes of Group B

Variable	MOISTURE STUDY SERIES 1300, 1926-30				ROTATION SERIES 1100 AND 1200, 1926-30			
	No. of Observa-tions	Mean of Class	Standard Deviation	Coefficient of Vari-ability	No. of Observa-tions	Mean of Class	Standard Deviation	Coefficient of Vari-ability
S—Cultivation	98	9.99±.33	4.91	49.19	240	11.39±.23	5.42	47.57
I—Interval between last previous harvest and nitrate sampling	98	12.85±.70	10.30	80.15	240	6.33±.24	5.64	88.49
Y—Total yield	98	1493±123.9	1819	121.83	240	1407±76.0	1747	124.19
N—Nitrate nitrogen	98	6.77±.38	5.68	83.96	240	6.83±.21	5.03	73.67

Relation of Factors in Group B

Correlation of factors Y, S, I, and N are shown in Table XXIII for Group B (period 1926-30) in both experiments. With relation to yield and cultivation, the rest interval was the dominating factor in the moisture study group where continuous culture with fallow has been followed. Under conditions of crop rotation, such was not the case. The Beta's were more nearly the same size and the multiple correlation was very much less.

A possible explanation of the apparently increasing importance of the rest interval, in a group where the average interval between the harvest of the previous group and the time of sampling is greatly extended, may rest in the fact that there are several months immediately following the harvest of a crop during which time the soil must recover a normal nitrogen-carbon ratio through decay of residues, and normal moisture and physical conditions before nitrate formation can be greatly accelerated. Reference tc Part IV indicates such a possibility where the line representing nitrate accumulation rises slowly at first but increases quite rapidly at a certain stage of the preparatory period before a balance is struck with those forces tending to remove solubles into the lower soil strata. It would therefore seem likely that, in the case of these moisture study experiments, the average time allowed between crops permitted a maximum nitrate formation before the succeeding crop began to draw upon the soil stores. On the other hand, the schedules used in the rotation experiments placed a new crop on the land enough earlier that maximum nitrate formation must have been reached at some time following the date of sampling. The average yields obtained would not indicate that less nitrates were available to crops on the rotation series than in the continuous and alternate culture series.

Table XXIII.—Correlation of Factors Relating to Nitrate Nitrogen Accumulation Group B, 1926-30

	(n98)		(Moisture Study Series 1300)		
	Y	S	I	N	Beta N
Y	1.0000	-.0352	-.6744	-.6279	-.2004
S		1.0000	.1397	.1513	.0562
I			1.0000	.7739	.6309
Multiple Correlation Rsiyn					.7890
	(n240)		(Rotation Series 1100 and 1200)		
	Y	S	I	N	Beta
Y	1.0000	-.2396	-.3108	-.4302	-.3003
S		1.0000	.1130	.2653	.1601
I			1.0000	.4062	.2948
Multiple Correlation Rsiyn					.5394

In general the observations made on soils subject to crop rotation bear out the conclusions arrived at from the single cropping experiments. A readjustment of the comparative importance of the few factors for which data were available leads to the expectation of great possibilities in the control of nitrate formation and disposition when it is learned just what results are economically desirable.

PART III

SIMPLE RELATION OF CROP HISTORY TO NITRATE ACCUMULATION

Since the customary routine of crop production more or less standardizes the value of some of the factors used in Parts I and II, it may be desirable to investigate the possibilities of crop history as a means of anticipating nitrate conditions.

Taking any single crop, for example wheat, the rest interval is practically uniform and the cultivation as to intensity and timing varies considerably less than for the group containing all crops with fallow. Likewise, total yields removed, and the raw organic matter carryover, vary much less within a group with a single crop history.

The data of the moisture study series, Tables I to VIII inclusive, are summarized according to uniform previous croppings in Table XIV. The data of the rotation experiments, Series 1100 and 1200, which were detailed in Tables IX to XVIII, inclusive, are summarized in Table XXV.

The standard error of estimate obtained from the consideration of eight fcators in Group A was 4.27 parts per million or 55% of the standard deviation of nitrate content of the whole group, which was 7.74 parts per million. Six of the cropping methods in this group possess standard deviations above 4.27 and six of them below. Four of the cropping methods with standard deviations below 4.27 are small enough that the crop history provides a better index of soil nitrate content than the statistical estimates based on the six or eight factors shown to have significant relations to nitrate accumulation. These are invariably crops which are particularly exhaustive of available soil resources, and the growing season of which extends into the latter part of the year.

Table XXIV.—Means and Variability of Nitrate Carryover in Topsoils Series 1300, 1923-30

Previous Crop	Number of Observa-tions	Means Nitrate Nitrogen P. P. M.	Standard Deviation	Coefficient of Variability
Two-year Plowed Fallow	10	21.70±1.93	9.06	41.75
Two-year Listed Fallow	5	15.45±1.82	6.06	39.22
Two-year Shallow Tilled Fallow	17	11.90±1.10	6.79	57.05
Plowed Fallow	9	14.28±1.14	5.10	35.71
Listed Fallow	16	10.14±1.00	5.95	58.67
Shallow Tilled Fallow	4	12.58± .90	2.68	21.30
Wheat Failure	14	13.00±1.60	8.92	68.61
Partial Fallow	2	12.56±1.53	3.20	25.47
Grain Sorghum 7' Row	14	4.21± .50	2.80	66.50
Grain Sorghum 3½' Row	31	2.39± .30	2.50	104.60
Wheat 8" Drill	28	4.27± .47	3.73	87.35
Sudan 16" Drill	14	1.72± .11	.65	37.79

Series Mean, 8.06.
Ave. C. V. 9 Corresponding Methods, 56.22.

Two of the methods having a standard deviation of less than 4.27 were represented by such a small number of observations that the probable error of standard deviation ranged very near in their upper limits to the standard error of estimate. Since all of the coefficients of variability which appeared to be especially low were attached to methods not represented throughout the period of 1923-30, it can only be concluded that the standard deviations are not strictly comparable to those derived from larger numbers of observations covering the full length of the period.

Table XXV.—Means and Variability of Nitrate Carryover in Topsoils Series 1100 and 1200, 1926-30

Previous Crop	Number of Observa-tions	Means Nitrate Nitrogen P. P. M.	Standard Deviation	Coefficient of Variability
Plowed Fallow	18	11.92± .76	4.82	40.47
Listed Fallow	11	10.87±1.20	5.91	54.36
Subtilled Fallow	8	10.32±1.08	4.56	44.16
Shallow Tilled Fallow	6	8.07±1.41	5.15	63.81
Spring Grain Failure	4	11.54±1.12	3.34	28.94
Wheat Failure	13	10.99± .83	4.48	40.76
Partial Fallow	4	12.82±1.50	4.45	34.71
Corn 7' Rows	15	7.35± .61	3.53	48.02
Corn 3½' Rows	5	6.77±1.22	4.01	59.23
Sorghum 7' Rows	28	7.03± .41	3.23	45.94
Sorghum 3½' Rows	21	3.96± .28	1.86	46.96
Beans 3½' Rows	30	7.16± .50	4.93	68.85
Wheat 8" Drill	37	3.65± .20	1.83	50.13
Spring Grain 8" Drill	19	3.37± .28	1.85	54.89
Sudan 16" Drill	5	2.10± .27	.91	43.33
Sweet Clover B. C.	10	6.39± .55	2.60	40.70
Alfalfa B. C.	4	1.94± .48	1.44	74.25

Series Mean, 6.83.
Ave. C. V. 9 Corresponding Methods, 46.71.

However, it may safely be concluded that thick stands of vigorously growing crops maturing in late summer or fall permit no opportunity of recovering a normal nitrate content in the soil by midwinter. Various methods of fallowing, and crops which mature earlier in the year or which are not especially exhausting to the soil, admit much greater possibilities of nitrate accumulation, but at the same time a much wider range of variation in which play the factors of climatic condition. Thus while a minimum nitrate accumulation can be surely expected after the fall harvest of a closely spaced sorghum crop, a maximum accumulation may or may not accrue after summer fallowing.

It will be noted that the mean soil nitrates of series 1300 was 8.06 parts per million, which is somewhat higher than that observed on series 1100 and 1200, 6.83 parts per million. The mean interval between cessation of cropping and sampling in the first instance was 12.8 months, while in the latter it was 6.4 months. The land devoted to rotation experiments, although cropped considerably heavier than that in the moisture study experiment, was still perhaps less heavily cropped than the average farm land in the surrounding country. Lacking the data for two important factors, it was not possible to calculate a standard error of estimate on the same basis as was done in Part I, but from the general similarity of the data, excepting its absolute values, it would seem that such croppings as sorghum in 3½' rows, wheat in 8" drills, spring grain in 8" drills, sudan grass in 16" drills, sweet clover broadcast, and alfalfa broadcast provide all the information needed to predict a low level of soil nitrate content at the end of the year.

Setting apart nine methods which were used in both experiments, the average coefficient of variability of nitrates was 46.71 when these methods were used in rotation, and 56.22 when used in single cropping systems. The average length of rest period being the greatest point of difference between the groups, it would appear that time elapsing between the stoppage of plant growth and sampling of the soil provides not only the greater possibilities of nitrate accumulation, but also the greater uncertainty of same.

PART IV

SEASONAL PROGRESS AND LEACHING OF NITRATES UNDER VARIOUS FIELD CONDITIONS

Seasonal Effects on Nitrate Accumulation

So far this study has been confined to the accumulation of nitrates in the surface six inches of soil. Table XXVI shows the progress of nitrate formation as represented by the accumulations present at different depths on eight plots of the moisture study series during the year 1929. In order to properly interpret these data, reference is made to Table XXVII which shows the daily rainfall for the period represented.

From April 15 to June 15 only small showers fell with the exception of one rain of 1.13 inches on the first of May. Gains in nitrate content were consistent and high in the surface six inches of all plots except those two which were listed in April. No crops were growing on any of these plots during this period. The rainfall for April 15 to June 15 was evidently not sufficient to carry down appreciable quantities of nitrate from the surface soil into the subsurface. Consistent gains in the second six inches were not noted on any of the plots. This period represents conditions under which nitrate forming organisms were active, having sufficient moisture and high enough temperature to bring about additions to the nitrate store of soil, but not enough rainfall to displace solubles accumulating in the surface layer.

The failure of plots 1309 and 1317 to gain in nitrate content during this period appears to have been, partly at least, the result of listing April 15, which disturbed the zone of bacterial activity, necessitating a period of adjustment to a different contour.

The period June 15 to August 15 had favorable temperature and soil moisture conditions, but enough excessive rainfall to cause considerable displacement of solubles in the upper layers of the soil. Nitrate formation, however, was rapid, and sufficient to replace topsoil leachings with gains in all instances except plots 1319 and 1321. These two plots were planted in milo at about the beginning of this period of observation. Serious depletion, however, was not noted on these milo plots during the first two months of crop growth. The plots which had been listed four months previous to August 15 began to make gains at this time and reached a level comparable with plots otherwise similarly treated but given level tillage.

From August 15 to October 15, one excessive rain came and nitrate formation did not quite keep pace with nitrate removals on fallow plots. Those growing in milo were exhausted to the usual low point noted after the removal of a sorghum crop.

The effect of numerous well distributed, moderate showers in increasing nitrification is well illustrated by the observations of the period October 15 to December 15. Although temperatures were becoming more adverse, the frequent showers during these two months, none being large enough to leach the topsoil, encouraged a considerable increase in all plots, including the ones from which a crop had just been removed.

The year 1929 came fairly close to representing the normal total and distribution of rainfall. However, the data of Table XXVI can not be accepted as strictly representative of a normal seasonal progress of nitrification but are of value to indicate the interplay of such factors as rest interval, cultivation and cropping as they affect nitrate accumulation and movement in the soil.

Table XXVI.—The Progress of Nitrate Formation Under Various Cultural Methods, 1929

			Nitrate Nitrogen in Parts per Million of Dry Soil					
Plot Number	Culture	Depth Sampled	April	June	Aug.	Oct.	Dec.	Seasonal Gain
1306	Wheat	0"-6"	2.32	9.18	20.54	16.46		
	Plowed	6-12	4.25	4.76	8.98	9.99	20.54	
	Fallow	12-18	6.25	10.40	8.98	11.32		10.79
		18-24	8.59	19.31	14.38	14.49	11.74	
Average			5.35	10.91	13.22	13.06	16.14	
1314	Wheat	0"-6"	3.29	11.26	15.97	10.82		
	Listed	6-12	1.66	3.25	6.53	6.96	13.69	
	Fallow	12-18	2.66	2.87	5.32	5.79		7.25
		18-24	2.97	3.14	8.45	6.55	6.09	
Average			2.64	5.13	9.06	7.52	9.89	
1319	Milo	0"-6"	2.52	9.65	5.53	1.51		
	Continuous	6-12	1.66	1.87	3.59	.61	1.49	
	Fall	12-18	3.53	3.06	1.65	.47		-.16
	Listed	18-24	4.10	2.37	1.65	1.14	4.09	
Average			2.95	4.23	3.11	.93	2.79	
1321	Milo	0"-6"	1.82	5.63	6.25	1.13		
	Continuous	6-12	2.32	2.51	3.26	1.14	9.13	
	Shallow	12-18	2.72	4.02	4.49	2.12		3.92
	Level	18-24	2.19	2.71	4.35	1.67	2.74	
Average			2.01	3.71	4.58	1.51	5.93	

Table XXVI—(continued)

Plot Number	Culture	Depth Sampled	Nitrate Nitrogen in Parts per Million of Dry Soil					
			April	June	Aug.	Oct.	Dec.	Seasonal Gain
1309	Fallow	0"-6"	1.90	6.13	14.38	12.71		
	Listed	6-12	8.29	7.15	8.98	4.67	12.69	
	Apr. 15	12-18	6.80	9.04	9.58	9.05		4.57
		18-24	13.60	9.65	15.97	12.87	11.74	
Average			7.64	7.99	12.22	9.87	12.21	
1310	Fallow	0"-6"	2.26	6.44	11.98	7.62		
	Continuous	6-12	7.16	6.80	7.98	4.99	11.74	
	Level	12-18	8.00	9.03	8.98	6.03		3.55
		18-24	11.33	11.59	11.98	8.37	11.74	
Average			7.19	8.46	10.23	6.75	11.74	
1317	Fallow	0"-6"	1.66	5.41	9.58	4.02		
	Listed	6-12	8.86	4.36	2.95	1.86	5.48	
	Apr. 15	12-18	3.58	2.25	3.59	3.49		-.50
		18-24	8.50	4.64	14.38	6.39	4.83	
Average			5.65	4.16	7.62	3.94	5.15	
1318	Fallow	0"-6"	1.92	4.82	7.19	10.35		
	Continuous	6-12	4.14	5.29	4.79	4.02	10.27	
	Level	12-18	6.80	9.01	6.84	4.02		3.65
		18-24	11.33	7.51	7.19	3.37	9.13	
Average			6.05	6.66	6.50	5.44	9.70	

Table XXVII.—Daily Rainfall 1929, Goodwell, Oklahoma

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
1	.01				1.13	.41	.38			.02		.01
2	t						.01			.01		
3		t				.01						
4	.20								.13	.11		
5	.09	.02		.11	t	.26						
6	t	t		t	.03	.33	.03		.11			
7		.02						.33	.02		.34	
8		.15			.02		1.03		.26		.76	
9					t		1.78	.13	.01	.03	.37	
10							.78		t			
11	t				.12					.09		
12					.35	.11				t		
13				.12	.30					t		
14				.01	t						.05	
15									.27			
16	t											
17					t							
18		t			t					.53		
19					t							
20				t						t		
21				t	t				t		.10	
22		t									.03	
23					.02	t		.02			.05	
24	t					.96	.54					
25		.02			t	.20	t	t				
26												
27			.62	t								
28			1.39					2.02		.13		
29	t		t				.07	.14	t	.02	.07	
30			.01		.25				.11	.20		
31			t									
TOTAL	.30	.22	2.02	.24	2.22	2.28	4.62	2.64	.84	1.14	1.77	.01

Since it is apparent that the slow movements of nitrates downward, particularly under conditions of heavy cropping, make possible the use of considerable quantities of available nitrogen which have lodged in the subsurface and subsoil layers, the question arose as to what extent the surface soil reading of nitrate carryover from one season to another might be indicative of the nitrate store present in the deeper root zone. Consequently, along with the usual surface soil sampling at the end of the 1930 season, samples were also taken of the plots 6"-18" deep. On the rotation series 1100 and 1200, forty-eight observations were available in which the surface soil mean nitrate content was 5.69 parts per million, being slightly higher than was found in the 6"-18" layer on the same plots, 5.09 parts per million. The correlation between surface 0"-6" and subsurface 6"-18" on these series was .7544±.04.

A similar determination on the moisture study series 1300 showed practically the same relationship as to size of means and correlation. The correlation here was .7764±.05.

A correlation between topsoil and subsurface nitrates with all observations in 1930, seventy in number, was .7561±.03. Considering that the widest possible range of cultural and cropping conditions existed in this group where the nitrates varied from .30 to 15.68 parts per million, the nitrate content of the topsoil may be accepted as a fairly reliable indication of the conditions existing to the depth of 18".

Extent of Leaching

Since it has been definitely established that the disappearance of nitrates from the surface 6" of the soil is closely related to the movement of moisture through the soil, as to amount and time and as to plant feeding, evidence has been sought to confirm the notion that the nitrates are largely subject to the same factors of disposition in the subsoil. The duration of nitrate accumulation in the deeper soil in concentrations equal to the maximum observed in the surface soil would indicate that slight chance of transformation prevailed in these relatively sterile areas and that variations in nitrate content were principally the result of physical transportation. In the following discussion the distribution of nitrates in the 6-foot soil section at the end of two consecutive years is shown, along with the soil moisture history extending over a period of four years under various systems of culture. In Tables XXVIII to XXXI inclusive, which contain the moisture and nitrate readings, the cropping period and yield removals are indicated below the tabulation for each plot.

Table XXVIII shows the relation of continuous milo culture to the moisture and nitrate movements in the 6-foot soil section for a period of four years, 1927-30 inclusive. It will be noted that the seasonal moisture did not penetrate below the first foot during 1927 on land where milo was growing. The planting of milo in 1927 coincided with the close of one of the most severe drouth periods on record (9). Although a fair amount of well distributed rainfall came during the growth of milo, the crop used it up as it fell and no moisture penetrated beyond the depth of the root zone until after the crop was harvested. Reference to Table XXX shows that plots seeded to wheat but which failed to mature a crop and which began the summer season with similar amounts of soil moisture experienced penetrations of moisture 1½' deep by June 13 and 4' deep September 28 the same year.

The remaining three years, 1928-30, were more typical of the moisture penetrations observed under milo culture with normal amounts of spring rainfall. In all cases moisture penetrated 6' deep or more at some time during the spring and early summer previous to the growth of milo. The results of this moisture accumulation are usually favorable to the pro-

Table XXVIII.—Movement of Soil Moisture and Nitrates During Continuous Culture of Milo, Goodwell, Oklahoma

Depth Feet	PER CENT OF SOIL MOISTURE Apr. 6 1927	June 13 1927	Sept. 28 1927	Mar. 3 1928	July 3 1928	Oct. 17 1928	Mar. 6 1929	July 1 1929	Oct. 26 1929	Nitrates P. P. M. Jan. 1930	% of Soil Moisture Feb. 28 1930	June 23 1930	Oct. 17 1930	Nitrates P. P. M. Jan. 1931
1	11.59	12.62	10.45	15.89	17.86	13.38	16.76	24.20	12.75	1.49	19.81	18.02	19.74	.65
2	11.87	12.19	12.03	10.51	17.86	12.99	14.82	23.36	12.30	4.09	14.48	17.08	13.95	.52
3	11.39	11.05	12.74	13.27	16.85	11.58	9.15	21.27	11.58	.78	16.08	10.44	12.72	.31
4	14.44	13.26	14.28	14.06	17.47	14.27	12.60	20.27	12.93	9.13	14.29	11.11	13.54	1.05
5	12.35	13.30	14.20	14.85	15.15	15.97	12.63	16.32	9.82	13.69	15.27	18.28	17.44	2.46
6	14.49	12.85	15.30	14.14	13.84	15.58	11.78	18.89	12.97	10.27	16.84	14.14	14.89	3.86
Cropping Period		X	X	X		X		X	X			X	X	
Yields Removed			3378			2680			1340				2680	
(Plot 1321—Stubble Through Winter)														
1	11.80	17.54	10.84	13.91	18.27	12.33	21.55	27.11	13.78	9.13	20.78	20.40	21.65	.60
2	12.03	12.78	11.03	10.76	20.47	13.10	18.62	23.42	15.25	2.74	16.32	16.01	20.00	.89
3	9.96	10.50	11.17	10.74	16.21	9.76	12.61	18.98	13.51	8.18	12.58	12.08	10.65	5.65
4	13.20	11.77	13.38	12.73	15.33	14.60	14.10	20.40	15.78	16.43	14.89	15.61	14.87	8.88
5	13.61	13.44	15.89	13.48	16.75	15.54	15.85	16.44	16.06	20.54	17.56	14.84	15.76	6.28
6	12.01	13.63	18.57	15.61	15.53	16.28	14.85	20.82	17.46	9.13	17.03	14.06	16.10	4.73
Cropping Period		X	X	X		X		X	X			X	X	
Yields Removed			2565			1265			1740				1840	

Table XXIX.—Movement of Soil Moisture and Nitrates During Two Years Summer Fallow after Wheat, Goodwell, Okla.

Depth Feet	PER CENT OF SOIL MOISTURE									Nitrates	% of Soil Moisture			Nitrates
	Apr. 6 1927	June 13 1927	Sept. 28 1927	Mar. 3 1928	July 3 1928	Oct. 17 1928	Mar. 6 1929	July 1 1929	Oct. 26 1929	P. P. M. Jan. 1930	Feb. 28 1930	June 23 1930	Oct. 17 1930	P. P. M. Jan. 1931
		(Plot 1306)												
1	19.97	15.20	22.33	20.54	10.22	19.17	22.07	22.10	16.39	20.54	24.47	23.71	25.41	4.97
2	20.95	21.03	21.64	20.31	11.47	12.39	15.79	20.01	20.13	11.74	22.20	20.57	22.81	4.65
3	20.96	19.38	20.31	18.52	10.16	11.62	10.01	14.12	10.43	27.38	17.02	15.27	17.77	5.55
4	14.14	15.58	15.32	15.28	10.62	11.28	9.44	11.65	11.38	20.54	13.93	12.26	14.68	14.40
5	10.79	13.59	10.82	15.87	7.67	9.17	6.67	8.63	10.22	16.43	10.83	10.48	10.19	12.00
6		12.68	8.94	16.87	8.59	10.31	10.53	10.49	10.51	20.54	10.75	13.28	13.89	14.40
Cropping Period Yields Removed	Fallow		X	-----------	X 7206			Fallow				Fallow		
		(Plot 1314)												
1	16.84	18.09	19.39	15.66	9.68	15.31	20.57	23.72	16.98	13.69	17.72	15.92	20.40	4.17
2	17.27	18.70	19.88	16.36	10.75	11.20	16.02	22.64	19.12	6.09	17.95	17.58	19.64	5.28
3	20.55	21.12	22.86	20.53	11.95	10.96	20.03	26.59	23.34	6.32	23.16	21.88	25.00	2.39
4	18.41	16.20	21.63	22.96	15.47	18.01	17.11	26.01	16.86	13.69	21.18	18.43	21.23	4.78
5	12.51	13.38	17.06	15.73	15.72	14.83	10.67	20.86	12.28	10.27	16.20	17.30	20.18	10.84
6	11.94	13.02	13.31	13.67	13.97	14.29	13.38	18.77	15.44	8.22	15.93	15.76	16.67	8.12
Cropping Period Yields Removed	Fallow		X	-----------	X 5173			Fallow				Fallow		

Table XXX.—Movement of Soil Moisture Under Continuous Wheat Culture

Depth Feet	Apr. 6 1927	June 13 1927	Sept. 28 1927	Mar. 3 1928	July 3 1928	Oct. 17 1928	Mar. 6 1929	July 1 1929	Oct. 26 1929	Feb. 28 1930	June 23 1930	Oct. 17 1930
						(Plot 1303)						
1	11.33	14.26	20.35	17.42	12.65	17.23	22.85	12.45	16.36	21.00	13.71	22.23
2	11.12	14.03	18.56	19.00	13.49	12.85	14.50	13.53	12.14	20.60	16.16	16.27
3	8.57	12.04	13.88	12.97	12.04	8.52	9.97	10.13	14.39	11.26	10.48	12.10
4	----*	11.52	10.97	12.32	11.13	10.75	9.62	9.77	9.75	10.95	10.96	11.11
5	----	15.82	11.01	----	10.47	14.02	12.63	12.79	----	14.08	----	----
6	----	14.74	----	----	12.36	12.95	14.82	17.75	----	15.23	----	----
Cropping Period	Failure		X----------	----------X		X----------	----------X		X----------	----------Failure		X------
Yield Removed				5002			1500					
			(Plot 1311)									
1	9.05	13.94	18.74	14.52	9.91	14.47	20.79	8.43	15.15	18.16	17.22	22.57
2	12.14	13.05	20.69	15.54	9.76	11.81	16.08	8.37	11.91	14.56	17.77	19.95
3	11.88	13.77	20.72	16.08	13.02	13.32	13.26	10.00	13.69	12.92	17.84	19.00
4	13.35	10.53	14.09	12.89	11.12	10.82	10.37	11.73	12.70	11.94	10.71	13.40
5	11.91	12.61	14.24	12.09	9.78	12.11	10.82	9.51	13.56	10.90	12.13	11.25
6	14.41	14.49	11.40	12.67	9.00	10.69	8.58	10.40	10.96	8.47	10.76	10.07
Cropping Period	Failure		X----------	----------X		X----------	----------X		X----------	----------Failure		X------
Yields Removed				4859			1280					

*Too dry to obtain sample.

Table XXXI.—Movement of Soil Moisture and Nitrates During Four Years Continuous Fallow, Goodwell, Oklahoma

Depth Feet	PER CENT OF SOIL MOISTURE									Nitrates	% of Soil Moisture			Nitrates
	Apr. 6 1927	June 13 1927	Sept. 28 1927	Mar. 3 1928	July 3 1928	Oct. 17 1928	Mar. 6 1929	July 1 1929	Oct. 26 1929	P. P. M. Jan. 1930	Feb. 28 1930	June 23 1930	Oct. 17 1930	P. P. M. Jan. 1931
		(Plot 1309)												
1	19.77	17.93	22.33	21.31	19.78	20.48	22.13	20.68	21.36	12.69	21.38	20.49	22.64	11.16
2	20.46	19.86	21.79	21.00	20.69	23.71	22.00	20.79	23.47	11.74	21.71	22.42	19.14	9.67
3	21.03	19.37	21.84	20.40	22.69	22.52	22.44	20.62	22.46	11.74	21.08	20.46	22.07	9.67
4	20.07	19.09	20.75	19.33	19.03	15.99	18.08	19.20	14.42	27.38	17.35	18.66	16.93	12.09
5	16.98	16.23	18.72	16.05	17.11	15.90	21.03	17.50	13.16	20.54	16.49	19.90	15.01	14.50
6	15.72	14.94	18.88	18.35	12.37	10.09	14.18	10.77	14.32	23.47	16.51	22.61	16.31	12.09
		(Plot 1317)												
1	14.71	16.47	18.20	16.69	17.51	22.10	21.81	23.33	19.57	5.48	18.63	18.93	19.77	6.91
2	15.56	15.90	18.86	16.27	17.71	19.24	19.69	20.44	17.42	4.83	17.26	15.44	19.43	6.01
3	16.77	16.30	20.86	19.23	20.38	20.70	21.54	23.88	21.45	7.47	21.32	22.03	22.93	5.71
4	12.04	18.48	20.20	18.49	22.43	20.54	24.95	25.23	22.14	14.94	23.98	22.66	25.14	7.13
5	16.97	17.55	16.51	16.40	19.36	15.83	20.94	22.62	18.92	16.43	20.43	17.71	21.02	10.38
6	12.04	14.79	13.35	14.34	18.84	20.04	19.25	23.17	19.00	20.54	18.22	17.68	25.71	9.69
		(Plot 1310)												
1	17.73	16.68	20.76	19.22	18.72	22.40	21.20	21.83	21.34	11.74	20.57	19.44	23.17	12.10
2	21.05	20.66	22.30	20.91	22.47	22.32	21.55	23.78	20.55	11.74	21.04	20.67	24.63	7.66
3	21.27	20.97	22.85	21.25	19.95	22.94	22.38	22.74	23.54	13.64	21.36	21.70	23.04	9.09
4	19.22	19.28	20.56	14.49	18.72	18.99	18.31	21.04	15.06	16.43	18.94	18.18	19.78	7.27
5	17.55	16.67	18.32	17.27	16.89	17.74	16.47	15.43	17.97	16.43	17.27	16.09	17.68	7.27
6	17.31	15.87	16.93	17.82	14.04	14.18	14.22	13.07	17.41	16.43	15.53	14.70	13.66	12.10
		(Plot 1318)												
1	14.50	15.38	17.96	17.00	17.01	21.17	19.10	25.36	20.16	10.27	19.29	15.69	21.87	3.10
2	15.01	15.62	18.12	16.37	18.98	20.61	17.27	20.00	17.93	9.13	19.39	16.44	21.86	5.21
3	15.99	15.92	18.87	18.58	20.30	22.73	19.84	22.55	21.59	8.22	20.15	18.89	20.40	6.75
4	19.38	17.26	20.31	19.80	23.66	26.60	22.20	25.42	21.15	11.74	23.19	19.23	24.11	7.53
5	18.56	16.35	20.76	19.24	20.31	20.21	20.54	27.34	19.00	14.94	21.59	17.26	21.53	10.69
6	17.12	14.71	18.85	16.14	20.52	22.45	18.98	21.54	21.36	14.94	19.58	16.46	19.40	7.65

duction of milo, making it the most dependable grain crop for the heavy type of soil in this area, but the amount of nitrates carried beyond reach of the crop roots before the crop comes on may be considerable. At the close of the growing season both in 1930 and 1931 the highest nitrate concentrations were found in the fourth, fifth and sixth foot of soil. Depletion of moisture by crop feeding has often been observed to a depth of five or six feet, but it appears quite likely that the exhaustion of nitrates which reach these depths is rarely completed and that leaching of nitrates beyond the extreme root developments is unavoidable where milo is growing continuously.

The manner of soil and moisture exhaustion by the wheat crop is illustrated by the records of two plots shown in Table XXIX, where wheat was introduced in the fall of 1927 after two years fallow and the land was again fallowed two years after the removal of the 1928 crop. It will be noted that moisture penetrated more than five feet deep during the year 1927, in spite of the long drouth ending in June that year, and by March 3, 1928, had entered or passed the sixth foot. The spring growth of the wheat crop beginning at that time, however by using the current rainfall as it came, not only prevented any further downward movement but depleted the original moisture store to the depth of four to five feet. Following the harvest of the 1928 crop one of these plots, 1306, was more nearly exhausted of moisture to the full depth of observation than was the other, and it regained its full carrying capacity more slowly during the two years following, thereby retaining a larger quantity of the accumulated nitrates. Seasonal moisture penetrated only into the third foot during 1929 on plot 1306. At the end of that year the highest concentration of nitrates was found in the third foot. Moisture penetrations reached through the fourth foot the following year, reducing the upper soil to a low nitrate content. In plot 1314 active moisture penetration was practically constant to a depth of 6 feet, and during the 17 months following July 1, 1929, nitrate reduction by leaching reduced the accumulations on this plot almost to the minimum point, which is shown in Table XXXI to become established under conditions of continuous fallow. Such a nitrate level was only reached in plot 1306 after moisture had penetrated the full depth of 6 feet. Running through the records of plots 1309, 1310, 1317, 1318 in Tables I to VIII, inclusive, will show that continuous fallowing accompanied by the final reduction of raw organic matter to a low point has resulted in a steady decline of nitrification beginning at three to four years after the last return of organic matter was made. The accumulation of undecayed residues with alternate cropping of wheat and fallow corresponds very well to that shown under continuous culture of milo in close spacing. The depth of leaching was also apparently about the same, although the frequency was less.

During the same period discussed above, 1927-30, the continuous culture of wheat has shown no considerable penetration of moisture beyond the depth of 4 feet. The average depth of greatest penetration in 1927 was 4 feet; in 1928, 2½ feet; in 1929, 2 feet; and in 1930, 2½ feet. As a consequence of the contrasting incidence of the cropping season upon the normal moisture distribution, quite different relations of moisture and nitrate accumulation and crop reliability are observed. The wheat crop, being established, is in position to make continuous use of spring rainfall from the beginning of growing weather and, unless premature failure occurs, can almost surely be depended upon to leave the soil within the root zone completely exhausted of nitrates and moisture at harvest time. The recovery of moisture content may then either begin immediately or be delayed by irregular and insufficient summer and fall rainfall. In any event the rapid continuation of nitrate formation must await the incorporation and partial decay of the wheat residues.

The well known relative reliability of the wheat and milo crops is brought about largely by the time of planting. While the approach of the planting time of milo brings the start of the crop nearer and nearer to the most dependably wet season of the year, the approach to seeding time of wheat leads toward the season of less amount and dependability of rainfall. The continuous surplus of carbonaceous residues which is built up by the single cropping of wheat prevents very large amounts of nitrates from accumulating to be carried over winter, and it is quite apparent that such cropping is most highly conservative of native nitrogen as well as of current moisture supplies.

The graph shown in Figure I portrays the time and depth of maximum moisture penetrations calculated as an average of duplicate plots of continuous milo culture, continuous wheat culture and continuous fallow for the seven-year period to date. Leaching has not progressed beyond 3 feet on wheat land except after crop failure, and it has regularly reached 6 feet or more on milo land excepting in years of extreme drouth.

The experiments at Goodwell have not run long enough to obtain conclusive information about the conservative effects of different types of crops upon the total nitrogen content of the soil. Preliminary analyses indicate similar relations to those shown by Gainey, Sewell and Latshaw of Kansas (10) in which the use of extended fallowing and the growth of sorghum crops caused large losses of nitrogen as compared with continuous and alternate small grain culture. The characteristic rainfall distribution of western Kansas being similar to that of the Panhandle of Oklahoma, only the variations in soils affecting penetration could effect a very great difference in the relation of factors determining the nitrogen balance of soil. This is probably not great enough to eliminate the large factor of leaching from a place of considerable importance in explaining the phenomena observed.

Wheat (or other winter grain crop) if grown continuously comes nearer to maintaining the seasonal fertility-moisture complex of native sod than any of the cultivated crops, and consequently is capable of a higher degree of conservation than crops requiring intensive cultivation and unnatural moisture accumulations.

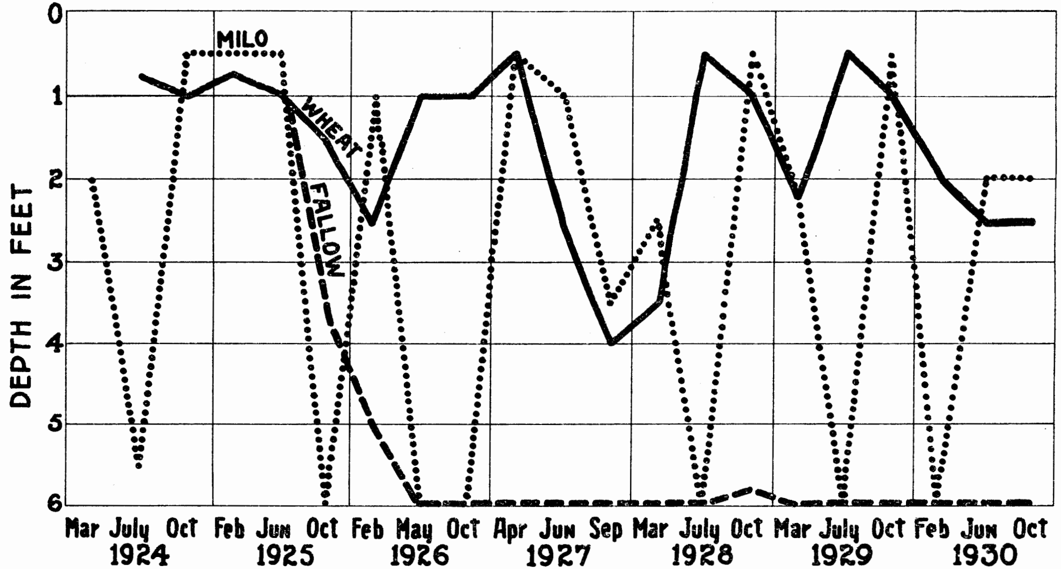
The sometimes excessive nitrate accumulations observed in High Plains soils have often been referred to as evidence of less leaching than is commonly experienced under more humid conditions. While this is undoubtedly the case it would appear in the light of the data at hand that the accumulations observed represent balances accruing faster than normal leaching can remove them in the absence of cropping, rather than totals in the form of cumulative reserves.

Therefore the appearance of excessive nitrate accumulation would seem to be strong evidence of past or immediate leaching losses. The nearest approach to complete conservation seems to be the use of a cropping system which, like continuous wheat culture, draws heavily upon the moisture during the period it would otherwise be accumulating and effectually ties up the available nitrogen by maintaining a restrictive organic situation during the time the land is unoccupied by a crop.

Table XXXI shows the moisture record of four plots fallowed continuously for four years in which, although the rate of leaching was not known, moisture has been continuously in progress downward through the 6-foot soil section since initial penetration was made.

The three conditions represented above are extremes in certain respects. Cultural and rotation experiments on the same soil show that the most productive sequence of crop is not one which would appear, from the present outlook, the most conservative. Just where a proper balance between profitable production and the conservation of fertility can best be established remains to be worked out.

FIG. 1 PENETRATION OF MOISTURE UNDER VARIOUS METHODS OF CULTURE—HEAVY SILT LOAM SOIL—GOODWELL OKLA.—1924-30



SUMMARY

I

A biometric analysis of eight factors found to be significant or of interest in relation to nitrate accumulation, for which 164 observations were available on heavy silt loam soil at Goodwell, Oklahoma, during 1924-30, showed the following relations to topsoil nitrate accumulations observed at the end of the year:

1. Rest period or the interval of time between the last previous harvest and nitrate sampling, which in this group averaged 12.8 months with a coefficient of variability of 88, was the most important factor favoring nitrate accumulation.

2. The distribution of effective rainfall was second in importance, as represented by the length of time next preceding the nitrate sampling which was required to supply an amount of effective rainfall sufficient to displace the topsoil moisture. The average for the group was 3.8 months with the high coefficient of variability of 160.

3. The number of excessive rains falling during the year (which roughly indicated the number of times the topsoil layer was leached) was third in importance, affecting nitrate accumulation adversely. The average number of excessive rains during the period studied was 5.1 annually with a coefficient of variability of 143.

4. Of equal importance to the number of excessive rains was the amount of topsoil moisture present during the winter. High nitrate accumulations were associated with a high winter soil moisture apparently as an index of reducing forces to which both nitrate and moisture were subject but which operated independently of the other factors studied. The mean winter topsoil moisture content was 16.6% with a coefficient of variability of 21.

5. The moisture content of the topsoil at the date of the first killing frost in the fall averaged 16.8%, and was only slightly more variable than the winter moisture, with a coefficient of 24. This factor was positively associated with topsoil nitrate accumulation.

6. Of equal importance to fall moisture content in relation to nitrate accumulation was the amount of cultivation given during the previous year. This was measured by taking the sum of the depths of all cultivations for the calendar year, and averaged 10.6 inches for the group with a coefficient of variability of 47. It was a fairly independent factor in increasing nitrification.

7. Total yields removed from the plots and the amount of raw organic matter carried over from one year to another showed little independent effects upon nitrate accumulation under the conditions of this experiment.

II

Comparing the relation of certain factors under conditions of single cropping and rotation revealed the following:

1. The relative importance of the rest period was much emphasized by extending it from 6.5 months to 12.8, suggesting the acceleration of nitrification after a certain stage of the decay of raw organic residues had been reached.

2. The heavier system of cropping practiced in the rotation experiments resulted in shifting some of the weight of influence governing nitrate accumulations from other factors to that of yields removed which exhibited a negative relationship.

III

1. Simple crop history of strongly feeding crops which mature late in the fall constituted a better index of topsoil nitrate content which may be expected to pass the winter than any available statistical method of estimate derived from massed data.

2. When the rest period was extended, or crops less exhaustive of soil resources were grown, the variation in topsoil nitrate accumulations became greater, the final result being subject to more hazards than in the restricted group.

3. The variability in nitrate accumulation resulting from comparable methods was somewhat less under conditions of crop rotation than under single cropping.

IV

A number of separate experiments covering different periods of time enable the following observations to be made regarding the movement of nitrates in the soil:

1. The downward movement of nitrates as a result of leaching appeared to be normally slow enough that considerable balances of nitrate nitrogen remained in the surface and subsurface soil, and that the surface soil nitrate content corresponded with that of the soil at depths of 6"-18" to an extent represented by the correlation coefficient $.75 \pm .03$.

2. Although the majority of uncropped plots reached the end of the year with a maximum amount of nitrates to depths of 24", there was a considerable variation in the progress of nitrification as a result of variations in culture and cropping during the year 1929.

3. Land producing a crop showed the highest nitrate concentrations at or soon after the beginning of the growing season.

4. Nitrate concentrations observed at various points in the lower subsoil corresponded closely to the depths surface water, as shown by moisture records, had penetrated during the preceding period.

5. Crops known to be particularly exhaustive of soil nitrogen under semi-arid conditions, such as sorghums grown in cultivated rows, were shown to allow regular leachings to take place beyond the depth of root growth as a result of manner of incidence of the growing season upon the normal moisture distribution.

6. Extended fallowing permitted excessive leaching.

7. Continuous wheat growing most effectively prevented leaching losses.

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