NITRIFICATION IN EGYPTIAN SOILS.

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The question of biological activity in Egyptian soils has never received adequate attention. Beyond the fact that nitrification was known to occur readily in Egypt as in most hot countries no series of regular observations has as yet been published dealing with the subject. The following results were obtained during a two years' study of the biological conditions of the soil of an Egyptian farm with a few observations further afield.

The Bahtim Experimental Farm of the Sultanieh Agricultural Society on which most of the work was done is situated ten kilometres north of Cairo and the soil of the farm is typical of the Nile alluvium. Owing to the large head of stock on the farm and the frequency with which fodder crops are fed on the land, the soil is somewhat richer than is usually the case in Egypt, but on the whole the conditions are typical of the normal farming conditions of the southern part of the Nile delta.

Much of the previous work on nitrification has been done under conditions of rainfall sufficient for or even in excess of agricultural requirements. The work of Pouget and Guiraud in Algeria[1] was carried out under a winter rainfall of 189 mm. as against 20 to 40 mm. near Cairo. The conditions in the north of the Delta in the winter months at least must be very similar to those of Algeria and similar results might be expected.

The only reference to nitrification in Egypt is that of R. Roche[2] who pointed out that nitrification goes on readily in Egyptian soils as soon as conditions are suitable.

Egyptian soil temperatures.

One of the most important factors controlling the activity of soil bacteria is that of temperature. During the first year of these observa-

[1] *Comptes Rendus*, 1909, **148**, 725.

[2] *Bulletin de l'Institut Egyptien*, Dec. 1907.

tions reliance had to be placed on the temperatures observed at the time of sampling, supplemented by the records of the Egyptian Ministry of Public Works, which however refer to the subsoil only. A regular series was started at Bahtim in 1918 and records obtained for the surface soil, the thermometer bulb being placed at a depth of 15 cm. The following table gives the monthly means of soil temperatures observed at Bahtim.

TABLE I.

Monthly means of soil temperatures at a depth of 15 *cm. Bahtim,* 1917–18. *Degrees centigrade.*

Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
21.	18	15·4	12·6	14·2	18·3	23·5	25·8	28·2	29·6	28·1	26·1

The biological processes in the soil should not then be normally limited in Egypt by temperature conditions, which at all times are seen to be favourable. Factors limiting such processes as nitrification must be looked for in other directions.

Egyptian agricultural conditions.

Agriculture in Egypt has always depended on the Nile water supply. With the exception of certain coast lands where dry farming is possible during the winter months and where the Bedouins raise a crop of barley, the rainfall is quite insufficient to supply the requirements of even the winter crops. The moisture content of the soil is therefore almost entirely dependent on the conditions of irrigation. The most important Egyptian crops are: Cotton, Maize, Wheat and Bersim (Egyptian Clover). Of these cotton is the most important financially. It is sown in February or March and occupies the ground until October and November. It is essentially a summer crop. Wheat and Bersim are winter crops; sown in October, November or December; they occupy the land until May or June. It is possible, however, to get a single cutting of Bersim just before the cotton crop. Maize is grown with the surplus of water that is available in the time of the Nile flood and is essentially a "Nili" crop. In Upper Egypt millet is grown as an early summer and Nile flood crop and beans as an important winter crop on the basin lands. In addition there are a number of special crops, such as rice, sesame, lentils, onions, henna, which demand special soil conditions and moreover find little place in the average farm rotation of Lower Egypt. Cotton is such a valuable crop that it is grown as frequently as possible, in most cases once in two years; under the best farming conditions however it would occupy not more than one-third of the land. A typical farm rotation is shown in the following table but many other combinations are possible.

TABLE II.

Farm rotation typical of Lower Egypt. (Three years.)

Cotton: March to October.
Bersim: October to May (four cuttings).
Maize (or Fallow): July to October.
Wheat: November to June.
Maize (or Fallow): July to October.
Bersim (or Fallow): November to January (one cutting).

Maize is not always grown on all the land available, a considerable proportion of the land will then be fallow from June until October as a preparation for wheat or early bersim. The amount of fallow land during the winter months will depend more or less on the quantity of bersim required to feed the farm animals.

So far as Egypt is concerned, no series of experiments have as yet been carried out with the idea of determining the best rotation to adopt; the effect on the soil of the frequent growth of cotton is not yet fully understood. In this connection, two points may be noted however: in the first place the yield of cotton per acre has been declining during the past twenty years and the decrease is not accounted for entirely by the attacks of insects like the Pink Boll Worm which has caused such enormous damage in late years. Even the theory discussed by W. L. Balls[1] concerning the pernicious influence of a gradually rising water table on the cotton crop is probably far from complete.

In the second place, good yields of cotton can be obtained without manuring. This is a fact now generally accepted by the Egyptian farmer and has been well demonstrated by carefully conducted field experiments. The cotton crop in Egypt at the present time is indeed independent of the artificial application of fertilisers[2]. Where definite increments in yield have been obtained, the increase has been too small or too uncertain to repay the cost of the manure.

[1] *Phil. Trans.* 1917, B. **208**, 157.

[2] *E.g.* F. Hughes, "Report on the manurial trials on Cotton carried out during the season 1908," *Yearbook Khedivial Agric. Soc.*, 1909, 154.

F. Hughes and H. C. Jefferys, "Manurial trials on Cotton carried out in the Stata Domains, 1910," *Agric. Journal Egypt*, 1912, **1**, 8.

V. M. Mosseri, "Note préliminaire sur les Engrais Chimiques dans la culture du cotonnier en Egypte," *Trans. 3rd International Congress of Tropical Agriculture*, London, 1914.

The important work of W. L. Balls on the physiology of the Egyptian cotton plant has thrown considerable light on the factors limiting the growth of this crop, and undoubtedly other factors, such as water supply and temperature, limit the growth and ultimate yield of the cotton crop far more than does the food supply.

As an outcome of the results obtained by the study of the soil of cotton fields during the past two years and described in the following pages, the writer has a suggestion to make concerning this problem of the nutrition of the Egyptian cotton plant, at least as far as the nitrogen is concerned.

The cereals of Egypt, however, are in a very different position. To persons accustomed to hear of the inexhaustible fertility of the Nile valley it comes somewhat as a shock to learn how dependent the maize and wheat crops are on nitrogenous fertilisers. The rapid increase in the sales of nitrate of soda during the past ten years and the exploitation of all local sources of nitrogen, such as the débris of ancient villages (Koufri), are signs that the fertility of Egyptian soils is indeed not permanent under the modern system of perennial irrigation. The lack of fuel is so pronounced in Egypt that all crop residues are gleaned from the land for this purpose and all solid excrements of farm animals are converted into fuel. At the time of writing, cotton seed cake, containing 4 % of nitrogen, is one of the most important commercial fuels of the country. The use of green manures, in the real sense of the term, is quite unknown in Egypt.

The value of the leguminous crop, Bersim, in maintaining the fertility of the soil is well known by the farmers themselves and when fed on the land a considerable proportion of nitrogen is added to the soil. Under these conditions the amount of nitrogen added to the soil by the bersim crop ought to be sufficient to carry forward the rotation of three years, with a little artificial aid to the maize crops.

The residues of the bersim alone without any return to the land in the way of animal excrements would seem however to be insufficient for the successful growing of cereal crops.

NITRIFICATION IN EGYPTIAN SOILS.

Up to the present time no definite series of observations has been made in Egypt concerning the activity of soil bacteria in producing plant food. Beyond the general statement by Roche, already mentioned, that nitrification does take place, no evidence for example is available concerning the intensity of the process as determined by the fluctuation of the nitrate content of the soil. In the following study, the amount of nitrate present in the soil has been taken as an index of bacteriological activity. This method has found successful application in other parts of the world and without doubt is one of the simplest and best. More recently, the determinations of soil nitrates have been supplemented by bacterial counts and by observations on the atmosphere surrounding the soil particles[1].

Under the conditions of the writer's laboratory, it has been difficult to supplement the nitrate values except in some special cases.

The amount of nitrate found in the soil at any moment is usually the result of the balance between crop requirements, drainage and nitrification. In Egypt there is little or no drainage under normal conditions, on the other hand other movements of soil water are of importance, such as the vertical movements due to capillarity and lateral movements due to seepage. In the first case salts accumulate on the higher portions of the soil such as the tops of ridges, while in the latter case considerable areas at lower levels are affected. In some cases nitrates in considerable quantities may be found out of the reach of plant roots on the tops of ridges which only receive water from below by capillarity. A case of this kind is quoted in connection with a maize field[2].

The case of fallow land with its accumulation of nitrates so well known in England is of special interest in Egypt. Fallow soils in Egypt may be and frequently are biologically dormant; in some cases, as in the basin lands of Upper Egypt, for several months each year. The water supply has been cut off and moisture conditions are therefore unsuitable. The fallow periods of the Egyptian farm rotation are particularly interesting on this account.

When a crop is grown on the land nitrate is removed from the soil fairly rapidly. In the case of wheat and maize there is usually no accumulation of nitrate in the soil, but the case of cotton is remarkable in that apparently, in the early stages of growth at least, nitrification is well ahead of the needs of the plant and appreciable quantities of nitrate accumulate in the surface soil.

[1] See for example: E. J. Russell, This *Journal*, 1914, **6**, 18; E. J. Russell and A. Appleyard, This *Journal*, 1915, **7**, 1; E. J. Russell and A. Appleyard, This *Journal*, 1917, **8**, 385.

[2] See also V. M. Mosseri, "Note préliminaire sur les sels nuisibles et le cotonnier en Egypte," *Trans. 3rd International Congress of Tropical Agriculture*, London, 1914.

Land in preparation for cotton.

There are two possibilities in the preparation of land for the cotton crop; either the land remains fallow after the preceding crop of maize or more usually a catch crop of bersim is grown, which enriches the soil somewhat but does not always permit of the thorough soil cultivation which the growing of cotton demands.

The winter fallow.

In the winter fallows of 1916–1917 and of 1917–1918 the progress of nitrification in the land in preparation for cotton was followed up. The preceding crop in each case was maize, which usually leaves little nitrate in the soil. In the first winter, the maize crop was harvested in November, 1916, and the land was first ploughed on December 4th. Repeated cultivations were given during the winter in preparation for the succeeding cotton crop. The rainfall may be taken at 40 to 50 mm. The moisture content of the soil remained remarkably uniform at 18 to 20 %, conditions which afforded a good opportunity for nitrification. Soil temperatures were about 16° C. Throughout the whole period there was a steady accumulation of nitrates in the surface soil from 9 parts to 23 parts per million of dry soil. After the final ridging for cotton on

TABLE III.

Nitrates in fallow land in preparation for Cotton. 1916–1917.

Date	Temperature at the time of sampling	Nitric nitrogen. Parts per million of dry soil	Moisture %
1916			
Nov. 13	—	9·0	19·2
Dec. 14	—	12·9	18·2
1917			
Jan. 15	15·2° C.	19·2	18·6
Feb. 14	15·0° C.	23·0	19·7
Mar. 6	17·0° C.	21·0*	16·2
Mar. 22	19·9° C.	35·5*	20·0

Agricultural operations.

1916.	Nov. 5	Maize harvested.
	Dec. 4	Ploughing.
	Dec. 27	Ploughing.
1917.	Feb. 15	Ridging.
	Mar. 6	Seed sowing.
	Mar. 8	Irrigation.

* In the subsoil (25–50 cm.) on Mar. 6 and Mar. 22, 14 parts per million of nitric nitrogen.

February 15th and up to March 6th there was no further increase in the nitrate content of the soil probably on account of the relative dryness. Immediately after the cotton was sown and watered the conditions became favourable and in sixteen days the nitrates increased from 21 to 36 parts per million. Table III gives the results of the 1916–1917 observations.

In the second series, carried out in 1917–1918, the maize was harvested at the end of October and 13 parts per million of nitrate nitrogen were present in the surface soil. In this case, however, the accumulation of nitrate during the winter was negligible. The soil was poor and the rainfall was less than in the preceding winter, so that there were few favourable opportunities when the moisture content of the soil was sufficiently high for active nitrification. As with the field of 1917, as soon as irrigation began, nitrification increased and an accumulation from 14 to 28 parts per million was observed in 20 days. In Table IV the results of the observations of the winter 1917–1918 are given.

TABLE IV.

Nitrates in fallow land in preparation for cotton. 1917–1918.

Date	Temperature at the time of sampling	Nitric nitrogen. Parts per million of dry soil	Moisture %
1917			
Oct. 31	22·0° C.	12·8	18·0
Dec. 19	14·9° C.	14·1	18·9
1918			
Jan. 28	14·0° C.	10·4	19·2
Feb. 28	16·3° C.	13·8	18·8
Mar. 23	19·0° C.	27·6	21·3

Agricultural operations.

Maize harvested	October 28, 1917.
Ploughings	Nov. 8.
	Jan. 4, 1918.
	Feb. 12.
Ridging	Feb. 23.
Seed sowing	Mar. 2.
Irrigation	Mar. 4.

The difference between the results obtained in the two winters is most probably explained by the difference between the rainfalls. In the following Table V the official records of the Egyptian Ministry of Public Works for the two stations nearest to Bahtim are given.

TABLE V.

Rainfall near Cairo, 1916–1917, *mm.*

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Total
Abbassia	0·0	2·5	1·5	29·8	13·7	1·5	49·0
Giza	0·0	3·8	1·6	17·3	9·0	0·0	31·7

Rainfall near Cairo, 1917–1918, *mm.*

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Total
Abbassia	0·0	7·5	3·2	0·5	4·4	15·0	30·6
Giza	0·0	1·4	3·1	1·1	2·3	12·0	19·9

In the first winter the rainfall was not only higher than in the second winter but was distributed as a small number of fairly heavy showers. At Abbassia 25 mm. fell on January 2, 3 and 4, 1917, and 7·0 mm. on February 10 and 11. In 1917–1918 more frequent, but very light rains were the rule; in only one or two cases did more than one millimetre fall in one day. Further in 1918 the bulk of the rain fell in March when the cotton was already growing on the land under observation. In 1917 the wettest month was January.

It is possible that the nitrification is not continuous, but occurs only after showers heavy enough to supply the necessary soil moisture. This would explain the differences observed between the two winters.

The bersim catch crop.

The growing of a single cutting of bersim during the winter preceding the cotton crop is very common as the extra fodder so obtained is very valuable. The amount of nitrogen returned to the soil in the excrements of the animals feeding on this crop together with the crop residues has been estimated by the writer to be not more than 55 to 65 pounds per

TABLE VI.

Nitrates in fallow soil after bersim catch crop. 1918.

Date	Soil Temperature	Nitric nitrogen. Parts per million of dry soil		Moisture %	
Jan. 9	12·4° C.	13·7		18·9	
Feb. 28	14·5° C.	14·7		16·4	
Mar. 23	18·9° C.	19·0		22·2	
May 8	25·0° C.	33·4	48·3	15·0	15·3
May 28	25·0° C.	28·5*	19·7	21·3	19·5
July 14	31·1° C.	28·3	25·3	6·5	10·7

* The subsoil contained nitrates: 13·7 parts per million. Irrigations were given on March 4 and May 16.

acre, that is, just about sufficient for the requirements of the cotton crop. Owing to the long growing season of the cotton crop and the active nitrification going on all the time, probably very little of this nitrogen is available for the crops which follow the cotton. The nitrification of the residues from the bersim catch crop was followed up in two cases, the land was irrigated occasionally and hoed to keep down the weeds, but was otherwise not treated.

The above results illustrate the necessity for water in keeping up the biological activity in these soils. The loss in nitrate indicated above may possibly be accounted for by denitrification, but on the other hand the results are very similar to those discussed by E. J. Russell and A. Appleyard in their second paper[1].

Nitrification under the cotton crop.

Observations extending over two years have been made on the fluctuations in the nitrate content of the surface soil of a cotton field. In 1917 a field of cotton was chosen under normal farming conditions, following the winter fallow which had been studied in the preceding winter. In 1918, a plot of cotton was chosen, the soil of which had received no manure for some years and which, judging by the yield of cereals, was in a fairly exhausted condition. The fallow period of this plot was that studied in 1917–1918.

In 1918 also, the early period of an experiment on the sowing date of the cotton crop afforded a suitable opportunity for the study of biological activity in the soil as affected by the different dates for the first irrigation.

The cotton field of 1917.

The results obtained during 1917 are given in the following Table VII. Determinations of soil nitrates were made as far as possible between each irrigation period.

The main feature of the conditions observed in 1917 is the relatively high amount of nitrate present in the surface soil of the cotton field at all stages of growth. The effect of irrigation in stimulating nitrification is shown in the observations made about the irrigation of June 21.

[1] This *Journal*, **8**, 403.

TABLE VII.

Amounts of nitrate found in the surface soil of a cotton field. 1917.

Date	Temperature at the time of sampling	Nitric nitrogen. Parts per million of dry soil	Moisture %
Mar. 6	17·0° C.	21·0	16·2
Mar. 22	19·9° C.	35·5	20·0
Apr. 30	29·0° C.	28·3	19·9
May 26	26·5° C.	22·5	16·8
Jun. 17	31·4° C.	16·8	15·6
Jun. 22	—	26·2	28·4
Jun. 26	27·6° C.	22·7	22·4
Jul. 10	28·0° C.	30·2	14·3
Aug. 1	27·0° C.	33·3	16·5
Sep. 4	25·5° C.	21·4	21·0
Sep. 15	24·8° C.	18·1	16·7
Oct. 24	20·5° C.	15·8	17·3

Agricultural operations.

March 6. Seed sowing.
March 8. Irrigation.

Other irrigations: March 22, April 28, May 25, June 21, July 12, July 31, August 19, October 2.

October 28. Plants removed from the ground.

The cotton field of 1918.

The characteristics of the observations made in 1918 are quite similar to those observed in 1917. The results are given in Table VIII.

TABLE VIII.

Amounts of nitrate found in the surface soil of a cotton field. 1918.

Date	Temperature at the time of sampling	Nitric nitrogen. Parts per million of dry soil	Moisture %
Feb. 28	16·3° C.	13·8	18·8
Mar. 23	19·0° C.	27·6	21·3
April 13	23·7° C.	16·8	18·9
April 17	22·1° C.	33·9	22·5
June 2	27·5° C.	60·0	16·3
June 25	27·6° C.	32·7	16·4
July 3	26·0° C.	33·5	13·5
July 20	29·9° C.	25·1	13·5
Aug. 28	33·2° C.	16·6	12·0
Sept. 10	26·4° C.	26·4	22·1

Agricultural operations.

Seed sowing: March 5.

Irrigations: March 5, April 13, May 23, June 16, July 4, July 22, August 6, September 5, October 5.

In 1918, a further study was made on a piece of land, which was under experiment for the sowing date of cotton. The land was rather rich and nitrification was followed up on the soil of plots sown on the 1st February, 1st March and the 1st April. The land was too dry before the irrigation of the cotton crop to allow of any bacteriological activity and it was possible to compare land under cotton with the corresponding fallow piece waiting for irrigation after a month's interval. Considerable quantities of nitrate were observed, up to 60 parts per million. The results indicate the rapid accumulation of nitrate that is possible in an Egyptian cotton field far in excess of the immediate requirements of the plant. See Table IX.

TABLE IX.

Amounts of nitrate found in the surface soil of cotton plots sown on different dates. 1918.

Date	Temperature of soil at the time of sampling	Nitric nitrogen. Parts per million of dry soil	Moisture %	Sowing date of cotton
Jan. 31	14·0° C.	25·1	17·0	
Feb. 16	15·9° C.	31·6	18·9	
Mar. 19	17·9° C.	42·7	20·4	Feb. 1
Apr. 16	23·4° C.	52·9	20·3	
May 16	27·0° C.	37·1	11·3	
June 25	27·7° C.	39·7	14·3	
Feb. 28	16·1° C.	17·0	17·8	
Mar. 19	17·9° C.	42·3	22·1	
April 16	23·4° C.	38·7	19·2	Mar. 1
May 16	27·0° C.	42·8	11·5	
June 25	27·7° C.	48·7	14·8	
April 1	22·8° C.	18·0	12·8	
April 16	23·4° C.	42·9	21·2	
May 16	27·0° C.	60·6	10·2	April 1
June 25	27·7° C.	48·0	14·1	

Irrigations—February plot: February 1, March 1, April 11, May 23, June 14.
March plot: March 1, April 11, May 23, June 14.
April plot: April 1, May 23, June 14.

The amount of nitrogen required by the cotton crop is stated by Foaden and Mackenzie[1] to be 59 pounds per acre. The writer has made two rough determinations of the nitrogen required at early stages of growth. The amount of nitrogen required in the first two or three months is more than supplied by nitrates produced in the surface soil.

[1] W. C. Mackenzie and G. P. Foaden, *Manures in Egypt and Soil Exhaustion*, Cairo, 1896.

In fact, quantities of nitrate nitrogen have been found at Bahtim in the soil of cotton fields quite sufficient for the growth of the crop to the end of the season. The cotton crop in Egypt is not therefore usually limited by the food supply. Table X illustrates approximately the relationship between the requirements of the cotton crop and the amount of nitrate formed in the soil by biological processes.

Table X.

Nitrogen intake of the cotton crop and nitrate production in a cotton field. Pounds per acre.

	May	June	July	Aug.	Sept.
Nitrogen required by cotton crop	4	—	40	—	60
Nitrates produced in surface soil	80	120	140	—	—
Root depth according to W. L. Balls[1]	50 cm.	90 cm.	150 cm.	180 cm.	200 cm.

The distribution of nitrate between soil and subsoil has not been followed up as yet. The movements of the salts in the soil with each irrigation would afford some clue as to what happens to the nitrates after they are produced. The only results obtained so far indicate, as would be expected, that the amount of salt in the soil bears no relationship to the amount of nitrate present. In each case the quantity present is the outcome of dissimilar factors. The results of W. L. Balls show that irrigation affects the moisture content of the soil down to considerable depths, so that there is no reason to suppose that the nitrate accumulated in the surface layer is never washed down far enough to feed the plant.

Table XI illustrates the lack of relationship between the amounts of salt and of nitrate in the soil of the cotton field of 1917.

Table XI.

Amounts of nitrate and of sodium chloride in the surface soil of a cotton field. 1917.

Date	Moisture %	Nitric nitrogen. Parts per million of dry soil	Sodium Chloride %
June 22	28·4	26·2	0·015
June 26	22·4	22·7	0·004
Sept. 15	16·7	18·1	0·010
Oct. 24	17·3	15·8	0·008

[1] This *Journal*, 1913, 5, 469.

Nitrification in a maize field.

The Egyptian maize crop grows exceedingly rapidly—in some sixty to eighty days the whole of the nitrogen required by the crop has been taken up and in consequence nitrification in the soil has to be very active to keep up with the requirements of the plants. Maize practically always follows the summer fallow or "sheraqi" and the period of ten days between the irrigation of the sheraqi and the sowing of the crop does not allow of much nitrate accumulation. Two cases were observed in 1917, one plot unmanured after wheat, and a second plot unmanured after bersim. After the first irrigation the amount of nitrate in the soil increased from 6 parts to 13 parts per million in nine days; during the period of growth the amount of nitrate in the land after bersim rose at first to 15 parts and then fell gradually to 5 parts per million as the maize took up increasing quantities of nitrogen, later rising again to 15 parts per million during the period of maturation of the crop. The corresponding plot after wheat shows a more steady content of nitrate, about 10 parts per million of dry soil. In neither case is there any marked accumulation of nitrate. The higher values obtained in the earlier and later stages after bersim reflect the higher nitrogen content of the soil after a leguminous crop. See Table XII.

TABLE XII.

Nitrates found in the surface soil of maize plots. 1917.

		After bersim		After wheat	
Date	Temperature at the time of sampling	Nitric nitrogen. Parts per million of dry soil	Moisture %	Nitric nitrogen. Parts per million of dry soil	Moisture %
June 26	—	6·1	6·9	5·4	5·8
July 5	25·5° C.	12·0	23·5	12·9	22·8
July 25	31·6° C.	15·3	18·5	10·6	19·6
Aug. 16	30·6° C.	8·1	13·7	9·9	15·5
Sept. 15	25·0° C.	5·4	21·4	11·1	20·1
Oct. 31	22·0° C.	14·8	21·7	12·8	18·0

Agricultural operations.

June 28. First irrigation of sheraqi.
July 7. Ploughing and seed sowing.
July 30, August 17, Sept. 20, Oct. 6. Irrigations.
Oct. 28. Maize harvested.

The amount of nitrate found in the surface soil of a maize field is frequently the outcome of factors other than those usually considered in the case of similar studies made under English conditions. Maize is a plant needing a considerable amount of space, and at the present time in Egypt there is considerable discussion concerning the spacing to be adopted and the special cultivation to be given. In a manuring experiment conducted at Bahtim in 1917 a system of cultivation on ridges was adopted which later experience showed to have been inadvisable. A number of nitrate determinations was made in this field and the relatively high values obtained, particularly at a time when the plant was most active in taking up nitrate, would indicate that the method of planting adopted resulted in a waste of nitrate as far as the maize crop was concerned. Some of the results are given in the following Table XIII. Apparently both the nitrate added to the soil in the fertiliser and that produced in the soil by biological activity is to an appreciable extent dispersed in the soil out of the reach of the roots of the maize plants.

TABLE XIII.

Amounts of nitrate found in the soil of a maize field. Cultivation on ridges. 1917.

Date	Nitric nitrogen. Parts per million of dry soil		Moisture %		Manuring (lbs per acre)
	Soil	Subsoil	Soil	Subsoil	
Oct. 1	16·7	11·4	19·4	17·0	Unmanured
	14·7	11·8	19·3	18·3	Nitrate of soda (333) applied in two dressings to crop
	19·4	14·4	19·2	19·5	Nitrate of soda (333) applied in one dressing before sowing
	17·9	18·0	18·5	18·7	Sulphate of ammonia (253) applied in one dressing before sowing

A further series of determinations was made at the end of the season in the case of an experiment on the spacing of the maize crop. The results are given in Table XIV.

TABLE XIV.

Amounts of nitrate and salts in the surface soil of maize plots. Bahtim spacing experiments. 1917. *End of season, Dec.* 22.

Method of planting	Nitric nitrogen. Parts per million of dry soil	Sodium Chloride %	Total Salts %
Ridges. Thick sowing ...	31·5	0·013	0·104
Ridges. Thin sowing ...	42·3	0·012	0·108
Flat. Thick sowing ...	20·4	0·016	0·100
Flat. Thin sowing ...	17·8	0·013	0·104
Tops of ridges. Thick sowing ...	601·0	0·074	0·652
Tops of ridges. Thin sowing ...	647·7	0·103	0·780

The above results indicate very clearly that the sowing of maize on ridges results in the waste of a considerable quantity of nitrate. The very high values obtained for the tops of the ridges show the effect of capillarity in the accumulation of soluble salts in the surface soil under arid conditions of agriculture. The high value for the sodium chloride and for the total salts is also an index of this factor.

As would be expected from the above considerations, the maize crop in Egypt responds readily to nitrogenous manuring, particularly to nitrate of soda.

The question of the relationship between the cultivation and manuring of the maize crop is illustrated by two series of experiments conducted at Bahtim during 1917 and 1918. In 1917 each treatment was repeated on five plots and the maize was grown on ridges; the results in Table XIII relate to this series. In 1918, each treatment was repeated on four plots and the maize was grown on the flat at two different spacings. The waste of nitrate on the ridges indicated in Table XIII is brought out in the yields obtained at the end of the season.

TABLE XV.

Yields of maize. Bushels per acre.

1917 Crop: cultivation on ridges	
Unmanured	31·1 ± 1·4
Nitrate of soda (333 lbs) applied before sowing	43·5 ± 0·9
Nitrate of soda (333 lbs) applied half before sowing and half at first irrigation	47·7 ± 2·1
Nitrate of soda (333 lbs) applied half at the first irrigation and half at the second	50·8 ± 3·1
Nitrate of soda applied at the first irrigation	49·2 ± 1·9
Ammonium sulphate (equivalent) applied before sowing	39·0 ± 1·1
1918 Crop: cultivation on the flat	
Unmanured	37·0 ± 1·9
Nitrate of soda (333 lbs), half at first irrigation and half at second irrigation. Close planting	62·8 ± 0·8
Nitrate of soda (333 lbs) applied before sowing. Close planting ...	60·2 ± 1·2
Ammonium sulphate (equivalent) before sowing. Close planting ...	61·2 ± 0·8
Nitrate of soda (333 lbs), half at first irrigation and half at second irrigation. Wide planting	58·8 ± 0·7
Nitrate of soda (333 lbs) applied before sowing. Wide planting ...	58·9 ± 0·5
Ammonium sulphate (equivalent) before sowing. Wide planting ...	59·8 ± 0·7

Close planting at 35 cm. Wide planting at 55 cm.

Nitrification under the wheat crop.

Wheat in Egypt usually follows the cotton or the maize crop, and on weak land responds to nitrogenous manures but not so readily as does maize. The few results tabulated below show that as in England nitrates do not accumulate under the wheat crop. The amounts of nitrate found in the stubbles of the wheat in the case of the summer fallow is a further illustration of this point.

Table XVI.

Amounts of nitrate found in the soil of wheat field. 1917–1918

Date	Temperature at the time of sampling	Nitric nitrogen. Parts per million of dry soil	Moisture %
1917			
Dec. 19	14·9° C.	15·5	20·2
1918			
Jan. 28	14·0° C.	10·4	19·2
Mar. 23	18·7° C.	7·4	24·0
June 2	27·5° C.	5·5	7·4

The summer fallow ("sheraqi").

One of the most characteristic periods of the Egyptian farm rotation is the period following the winter crops. The land is already in a fairly dry condition when the crop is removed and it is allowed to remain fallow without treatment of any kind until sufficient water is available for the "Nili" crop. The earliest date at which the first irrigation of the sheraqi is allowed is fixed by law and depends on the prospects of the Nile flood. A very intensified form of sheraqi is observed in Upper Egypt on the basin lands which only receive water at each Nile flood and are fallow from May until August. A number of nitrate determinations was made on sheraqi soils immediately after the removal of the winter crops in some cases, and in others after an interval or just before the irrigation. The moisture after the removal of the crop may be fairly high according to the previous irrigation of the field, but the soil soon dries out and the moisture content falls to 6 or 7 %, or a little below the air dried condition that is reached under laboratory conditions. The preceding crop has removed most of the soluble nitrogen from the soil. Even after bersim little nitrate is found unless stock have just been feeding on the land. See Table XVII.

TABLE XVII.

Moisture and nitrate content of "sheraqi" soils.

Date	Preceding crop	Temperature at the time of sampling	Nitric nitrogen. Parts per million of dry soil	Moisture %
1917				
May 3	Flax*	21·0° C.	2·7	14·2
May 3	Flax†	—	2·7	15·5
May 26	Wheat	31·0° C.	4·7	15·4
May 30	Wheat‡	—	7·3	7·1
	Wheat‡	—	8·0	7·4
	Wheat§	—	15·4	7·7
	Wheat§	—	11·7	8·3
June 26	Wheat	31·0° C.	5·4	5·8
June 26	Bersim	—	6·1	6·9
1918				
June 2	Wheat	27·5° C.	4·3	8·5
Aug. 8	Basin Assiut	36·0° C.	6·8	3·8
	,,	—	5·7	3·7

* Flax manured with farm manure.
† Flax manured with nitrate of soda.
‡ Wheat: unmanured plots.
§ Wheat: nitrate plots.

The general conditions of the sheraqi include fairly high temperatures. At Bahtim in June, 1917, just before the irrigation the highest temperature observed was 35° C. at 10 cm. below the surface. At Assiut in August, 1918, on a basin 46° C. was observed but undoubtedly higher temperatures are the rule during the months of June and July. As might be expected no bacteriological activity can take place under such conditions and nitrates do not accumulate in sheraqi soils. The number of bacteria is also low, usually not more than one million per gramme of dry soil. See Table XVIII.

TABLE XVIII.

Bacteria present in sheraqi soils. Millions per gramme of dry soil.

	Bacteria	Moisture %
Wheat soil. Bahtim, 1917 ...	2·0	7·0
Bersim soil. Bahtim, 1918 ...	1·6	4·1
Basin soil, Assiut, 1918. Hod el Zenar	1·1	3·8
Basin soil, Assiut, 1918. Hod el Zenar	1·0	3·7
Basin soil, Shotb village, 1918...	0·8	5·3

The normal number of bacteria in the soils of Egyptian fields appears to be about 10 to 15 millions per gramme of soil.

It might be expected that as soon as conditions again became favourable for biological activity, an abnormal increase in such processes as nitrification would take place. E. J. Russell and H. B. Hutchinson[1] suggest that prolonged drought or prolonged heating at 40° C. acts on the soil in the same way as partial sterilisation by heat or by volatile antiseptics. No doubt in the case of the basin lands some such action does occur and to a less extent in the ordinary sheraqi soils of Lower Egypt. The conditions are not quite stringent enough in the case of the latter soils to kill off all the protozoa which are readily found in sterile hay infusion which has been inoculated with sheraqi soil. In the case of the basin samples however, very few protozoa developed, chiefly ciliates, and these were by no means vigorous. The proof of the partial sterilising effect of the sheraqi conditions is rather difficult to obtain, as it is obviously difficult to keep the same soil untreated for comparison. The writer has made preliminary attempts to settle this interesting point, but further study will be necessary before final evidence can be obtained.

The summer fallow subsequent to the sheraqi period.

Frequently after a bersim crop, the summer fallow is extended beyond the sheraqi period until the winter, when a crop of wheat is grown. The irrigation necessary is given after the requirements of the maize crops have been satisfied. During the summer of 1917, the amount of nitrate accumulated in such soils was determined in a few instances. A piece of land after wheat, reserved for such a fallow, showed an increase in nitrate content from 14 to 23 parts per million in one month. Another piece of land after bersim contained 26 parts per million on the 3rd November after being fallow all the summer; in this case no special effort had been made to keep the soil moist after the first irrigation and ploughing. The possibilities of the active summer fallow were illustrated, however, in the case of two fallow pots containing forty kilos each of soil, which were kept at 20 % moisture content for three months during the summer of 1917. The amount of nitrate in the soil increased from 10 parts to 250 parts per million during this period. Under practical conditions it would hardly be possible to obtain such active nitrification in the summer fallow—and possibly not advisable to attempt it. All that is necessary is to obtain a sufficient accumulation of nitrate in the soil to give the wheat crop a good start, relying on the

[1] This *Journal*, 1913, 5, 152.

nitrification under the wheat itself for the ultimate requirements of the crop.

Effect of a growing crop on nitrification.

It has been suggested that the growing crop influences the biological activity of the soil. The general opinion seems to be that nitrification in a cropped soil is not so active as in the corresponding fallow soil. In the case of the maize crop, however, T. L. Lyon and J. A. Bizell[1] suggest that the effect of the crop is to stimulate nitrification. In the case of Egyptian soils it is almost impossible to compare cropped soils with fallow soils under field conditions owing to the enormous variation in the water content of these soils. A number of data from pot experiments are available, however, and are of sufficient interest to be included in this paper.

TABLE XIX.

Effect of maize crop on nitrification in the soil.
Pot experiment. 1917.

Date	Soil moisture %	Nitrogen in crop gm.	Nitric nitrogen found in pot gm.	Total nitric nitrogen produced gm.
Aug. 2	7	0	0·39	0·39
Sept. 11	22	0·68	1·40	2·08
Oct. 2	19	1·60	0·63	2·23
Nov. 7	24	1·30	0·79	2·09
Nov. 18	20	1·54	0·72	2·26
Nov. 18	20	Fallow pot	5·76	5·76

TABLE XX.

Effect of a wheat crop on nitrification in the soil.
Pot experiment. 1917–1918.

Days	Soil Moisture %	Nitrogen in crop gm.	Nitric nitrogen found in pot gm.	Total nitric nitrogen produced gm.
0	—	0	1·38	1·38
78	14	0·73	0·94	1·68
112	15	1·37	0·70	2·07
176	18	1·34	0·61	2·04
176	—	Fallow pot	3·68	3·68
0	—	Fallow pot	1·38	—
23	—	—	1·87	—
71	—	—	2·61	—
129	—	—	3·68	—

[1] *Journ. Franklin Inst.*, 1911, Jan.

These results would indicate that the root activities of a growing crop have some limiting effect on the production of nitrate in the soil. In both cases the fallow pots have accumulated appreciably more nitrate than have the cropped pots. The difference between the results obtained with maize by Lyon and Bizell and those reported above is probably to be explained by the fact that in the United States the maize crop is given much more space than is usually the case in Egypt. The maize plants in the pots were certainly overcrowded.

Sampling and determinations.

The plots to be investigated were sampled with a soil borer to a depth of 25 cm. in at least four places and the sample brought to laboratory immediately. Duplicate lots of 250 gm. each were dried at 55° C. as in the Rothamsted method and the nitrates washed out on a Buchner funnel with distilled water. The reduction to ammonia was carried out in alkaline solution with Devarda alloy or preferably by means of a mixture of zinc dust and reduced iron.

CONCLUSIONS AND SUMMARY.

An attempt has been made to determine the intensity of the biological processes in the soil during the most important periods of the Egyptian farm rotation. The fluctuations of the nitrate content in the surface soil have been taken as the most important index of this activity.

In all cases the moisture content of the soil limited these processes more than any other factor.

There was observed throughout the season in a cotton field a relatively large amount of nitrate, more than sufficient for the immediate needs of the cotton plant. The lack of response on the part of the Egyptian cotton crop to nitrogenous fertilisers may be accounted for in part, if not entirely, by the fact that nitrification in the soil is well ahead of the needs of the crop.

Nitrification under wheat and maize shows in general the same characteristics in Egypt as in other parts of the world; there is no accumulation of nitrate in the soil.

The winter fallow, depending for its water on the rainfall, may be a period of steady nitrification when the amount of the rainfall is sufficiently high.

The "sheraqi" soils of the summer fallow are biologically dormant. They are characterised by very low moisture content and by fairly high temperatures, particularly in the basins of Upper Egypt. There is a probability that these conditions act as a partial sterilisation of the soil.

Pot experiments are described concerning the effect of the growth of maize and of wheat on the accumulation of nitrate in the soil.

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