FLUCTUATIONS, RECUPERATION AND FIXATION OF NITROGEN IN THE SOILS OF WESTERN INDIA.

By D. L. SAHASRABUDDHE, *M.Sc., M.Ag., Agricultural Chemist to the Government of Bombay.*

(*Read at Symposium, August 29-30, 1936.*)

I

This paper gives a short account of the work done on soil nitrogen at the laboratory of the Agricultural Chemist to the Government of Bombay, Poona.

The problem as to how the fertility of Indian soils is maintained in the absence of manure, more particularly in the arid and semi-arid tracts like the Deccan, has always been a difficult one. More especially the maintenance of the available nitrogen is difficult to explain. On the one hand, there is a demand on the accumulated stocks of nitrogen from the crop grown. This reaches, in the case of an annual crop of Jowar (*Andropogon Sorghum*) grown without manure, to about 20 lbs. of nitrogen per annum for such a crop (700 lbs. grain and 2,000 lbs. straw) as is commonly produced in the Bombay Deccan. Then there is the annual loss from drainage and from denitrification.

It would seem certain, therefore, that even in the absence of vegetation, there must be considerable fixation of nitrogen from the atmosphere.

The soil used for the work was obtained from Pashan village, five miles from Poona. It had been cropped every year, but without any leguminous crop or any manure for ten years. There had likewise been no irrigation, and the annual crop was either Bajri (*Pennisetum typhoideum*) or Jowar (*Andropogon Sorghum*). It was a typical ' medium black soil ' of the Deccan.

To begin with, it was decided to find out the effect on the nitrogen of the soil of varying the quantities of moisture, and also of varying the temperature and the light conditions of the soils, and also the effect of additional lime in each of these cases.

Effect of varying the quantities of moisture.—The following table gives the milligrammes of organic and ammoniacal nitrogen per 100 grm. of soil kept at 20°C. in the incubator.

TABLE I.

	1st day	After 35 days	After 70 days	After 105 days	After 140 days	After 175 days
	Milligrammes per 100 grm. of soil					
Soil containing 30 per cent moisture.	33·01	48·55	35·18	30·73	25·00	26·21
Soil containing 20 per cent moisture.	33·01	42·00	33·79	30·77	..	23·93
Soil containing 6·6 per cent moisture.	33·01	31·38	29·80	25·61	22·64	..

From the above table it is evident that the higher the quantity of water the higher is the amount of nitrogen fixed. It seems that during the first thirty-five days nitrogen is fixed and then during the next period the amount decreases. After this also it continues to go down upto at least 175 days. It must be remembered that the figures present the algebraic sum of the fixation and the loss of nitrogen, since both these actions are likely to go on side by side. It is also possible that the smaller figures may be due to nitrification.

Effect of temperature.—The trays kept at 20°C. represent a low temperature, those at 40°C. represent a high temperature, while those kept in diffused light were between 20°C. and 27°C. for the first three months and therefore represent an intermediate stage. After 35 days all the samples show a fall in the nitrogen contents, and hence the figures for the first 35 days only are shown in the following table. The figures are in milligrammes of organic and ammoniacal nitrogen in 100 grm. of soil.

TABLE II.

	30 Per cent moisture	20 Per cent moisture	6·6 Per cent moisture
	Milligrammes per 100 grm. of soil		
40°C.	55·01	44·31	35·21
Diffused light	49·98	47·07	38·14
20°C.	48·55	42·00	31·38

These figures clearly indicate that the largest quantity is fixed at a temperature above 20°C., but at 40°C. it is lower than at temperatures between 20°C. and 27°C. It seems that a high temperature like 40°C. slackens the activity of fixing nitrogen or hastens nitrification.

Effect of additional lime.—First set. To find out the effect of additional lime, three per cent of calcium carbonate was added to the soil although it already contained excess of calcium carbonate.

The experiment showed that additional lime brings about more nitrification, but the total nitrogen throughout the period of 84 days is greater in the original than in the same soil with additional lime.

Effect of light.—From the results obtained during the experiments no definite relation of the increase of nitrogen to the intensity of light can be shown, but it is certain that even in darkness the fixation goes on.

In the first two series it was found that after about thirty-five days from the time of exposing the samples, the highest figure for increase of nitrogen was obtained and after that there was a regular fall. When the soil was taken for experimental purposes it was air-dry containing about 6 per cent water, and it was this soil that showed fixation when water was added. It seems,

therefore, that when a dry soil gets water it begins to show this activity of fixing nitrogen. In order to find out the extent to which this property proves to be useful in increasing the nitrogen contents of the soil a third series of experiments was taken up.

The conclusions that can be drawn from this series are :—

When the soil gets water the nitrogen begins to increase for some time and then a fall commences. If at this juncture the soil is dried at 60°C. and then gets moistened again, the nitrogen increases further, for four and five weeks more, and then begins to go down. Repeated drying does not increase the nitrogen contents beyond a certain limit under the given conditions.

II

This is only a continuation of part I. It gives the results of experiments done with different typical soils of the Bombay Presidency. It also records the results of experiments done to find out the effect on nitrogen recuperation of added (*a*) lime as calcium carbonate, (*b*) phosphatic substances, (*c*) organic matter and (*d*) alkali salts.

The soils alone or with additional substances were kept at 35°C. in an incubator. All the soils had water equal to one-third the water-holding capacity.

Effect of addition of lime.—In order to ascertain the effect of additional lime on soils with different percentages of original lime, experiments were done on Goradu soil from Nadiad, River silt from Poona, and Laterite soil from Belgaum by adding 3 and 5 per cent of calcium carbonate.

TABLE III.

	Original lime as $CaCO_3$	pH value	Nitrogen fixed per 100 grams. of soil over the original nitrogen
	Per cent	Per cent	Per cent
Medium black soil	7·96	8·35	21·17
Goradu soil	2·36	8·22	6·36
River silt soil	1·30	8·18	5·6
Laterite soil	0·44	5·99	2·17

TABLE IV.

Soil	Original lime per cent as calcium carbonate	Milligrams of nitrogen fixed over that in the control	
		3 per cent lime added	5 per cent lime added
	Per cent	Per cent	Per cent
Medium black soil	7·96	*nil*	*nil*
Goradu soil	2·36	2·6	2·71
River silt soil	1·30	4·09	8·70
Laterite soil	0·44	4·55	8·40

As shown in series I, the Medium black soil which already contains a high proportion of lime is not benefitted at all by additional lime while all the other soils are benefitted. In Goradu soil with 2·36 per cent of original lime, addition of 3 per cent shows some increase in the power of recuperation, but 5 per cent addition does not show any distinct advantage over 3 per cent, because the addition of 3 per cent is enough to make up the required proportion of lime and the extra 2 per cent has, therefore, no effect.

Effect of Phosphatic Substances.—Phosphoric acid is one of the important plant food constituents. In a suitable form it is found to be beneficial to the crops and to small organisms. The addition of phosphorus to a soil has been found to increase the amount of nitrogen fixed.

If phosphoric acid, in the form of superphosphate, is added to soils their nitrogen recuperation power is increased. In the quantities used, the larger quantity of phosphoric acid has a better effect than the smaller quantity.

Effect of addition of organic matter.—Goradu, River silt and Laterite were the three soils selected for experiment. They contain different proportions of organic matter. Cane sugar was added in solution in two proportions —2 per cent and 4 per cent. Water was added to make up to one-third the water-holding capacity of each soil and all the samples were incubated at 35°C.

Addition of 2 per cent sugar shows a beneficial effect in increasing nitrogen fixation power and a further addition of 2 per cent shows a further small advantage with the three soils under experiment. The smaller the proportion of original organic matter the greater is the effect of added organic matter. Addition of sugar has a deleterious effect on the nitrifying power of the soil at least for some time.

The alkali salts—sodium carbonate, sodium sulphate and sodium chloride —when added to medium black soil of the Deccan, and Goradu and Laterite soils show a deleterious effect on the nitrogen recuperation power of these soils. Sodium carbonate is the most and sodium chloride the least harmful of the three.

The alkali salts have the worst effect on the medium black soil while their effect is the least on the Laterite which is an acidic soil. The alkali salts with the quantities used in the experiments show a stimulating effect on the nitrogen recuperation power of the River silt soil.

The River silt which is a freshly deposited soil is easily stimulated by the addition of lime, phosphoric acid or organic matter and is also stimulated by the addition of small quantities of alkali salts in increasing its nitrogen recuperation power.

III

The above results definitely prove that, at least under the controlled conditions of the laboratory, the additions of phosphatic substances and organic

matter improve the nitrogen recuperation of such soils as are not originally rich in these ingredients. But it remained to be seen whether any recuperation of nitrogen takes place actually under field conditions where there is repeated wetting and drying of soils by rain and heat. It was therefore necessary to determine whether the fixation of nitrogen takes place under field conditions, just as it does in the laboratory. Such a suitable place was found at the Dry Farm Experiment Station at Manjri about 8 miles to the east of Poona. Under the dry arid conditions of the Deccan nitrogen is liable to far greater losses than any other plant food ingredients and from 1927 onwards nitrogen determinations were made every year sometime after the harvest of the crop.

The figures indicated rapid depletion of soil fertility. But the decrease in nitrogen contents of the soil was not found to have resulted in lowering the yields from these plots. Further, there was a similar depletion of nitrogen from a plot which received farm yard manure.

It was therefore decided to carry on a series of determinations of the total nitrogen contents of soils receiving different treatments of cultivation and manuring throughout one complete year taking the soil samples once every month.

It is interesting to trace the change in nitrogen content of well cultivated plots in comparison with the actual soil temperatures observed together with the moisture contents of the soil from month to month as given in the table below :—

Total nitrogen in 9″ surface soil together with corresponding soil moisture and average monthly soil temperature.

TABLE V.

Months	Total nitrogen milligrams in 100 grammes of oven dry soil	Per cent moisture	Average monthly soil temperature ; average of temperature at 3 and 6 inches depth from surface
July, 1930	73·6	25·6	27·3
August, 1930 ..	98·1	24·1	28·6
September, 1930 ..	80·9	28·1	27·4
October, 1930 ..	99·4	25·9	29·5
November, 1930 ..	102·1	22·3	27·8
December, 1930 ..	121·6	20·2	29·5
January, 1931 ..	118·3	17·7	30·4
February, 1931 ..	118·3	14·4	31·9
March, 1931	108·7	11·3	34·4
April, 1931	107·9	8·0	39·3
May, 1931	100·6	13·6	40·3
June, 1931	105·8	16·3	....

When the determinations were commenced just after the middle of July the monsoons had just set in and had moistened the upper six-inch layer of the surface soil. The soil temperatures which were high, going up to 40°C., had come down giving an average soil temperature of 27·5°C. The nitrogen content of the soil was then at its minimum being 73 milligrams per hundred grammes of the soil. The effect of wetting by the monsoon rains together with a slight rise in soil temperature was to increase the nitrogen to 98 milligrams or a rise of 33 per cent in a month's period after the original determination. The heavier rain in the month of September amounting to 5·75 inches, combined with a fall in temperature by over a degree, resulted in lowering the nitrogen content to 80 milligrams or fall of 17 per cent over the previous determination. The next determination again showed an increase in nitrogen to the extent of 34 per cent over the original. There was a little more than 3″ of rain during this period but the average temperature had increased by over 2°C. In the following month there was a slight rise in nitrogen but the peak of the curve reached its highest in December. There was practically no rain between the determinations of November and December and the average soil temperature was higher than ever before, since the commencement of the experiment. The maximum rise in nitrogen contents was as much as 65 per cent over the original. During the next two months the nitrogen remained fairly high under the high temperature of January and February. Then a steady fall in nitrogen continued throughout the following four months from March to June with a steady lowering of the moisture contents of the soil, though there was a steady rise in temperature. At the end of the twelve months period of experiment the soil was left richer in its nitrogen contents than at the commencement, being nearly 43 per cent higher. The land was occupied by a crop of *Rabi Jowar* from the 17th of September 1930 to the 14th of February 1931. In spite of the presence of the crop on the land, it was freely exposed to the sun, rain and wind, as the plant population on the experimental plot was very limited. The crop was sown by dibbling 2 seeds 18 inches each way. The roots and leaves of the plants if obtained in the soil sample were carefully picked up and removed so as to avoid any addition of nitrogen due to their inclusion.

Nitrate and nitrite nitrogen.—It is interesting to see the nitrate and nitrite nitrogen changes in the soil under field conditions. Nitrogen in these forms was probably at its lowest on the starting date. But in a month's period it reaches its maximum peak in August. The moisture content of the soil during this month was about 24 per cent and the temperature was rising. The moist soil was stirred on the 28th July after the first determination. Under those conditions nitrification took place very vigorously and gave the maximum figure for nitrate nitrogen. The moist soil had undergone stirring twice during October on the 1st and 16th of that month and once again in November on the 11th and as a result the nitrate nitrogen again increased during October and November when a second peak was obtained. It decreased considerably

in the following month and remained practically low throughout the cold weather months of January, February and March. Ploughing the land in March and subsequent slight wetting of the surface soil raised the nitrate nitrogen in the following three months of April, May and June. Clarke and his associates also found two peaks for nitrate accumulation under the climatic conditions of the United Provinces.

The first series of determinations described was done on a piece of land which was under a crop receiving special care, attention and treatment. But an ordinary cultivator is not likely to follow the procedure and treatment of land as given there and hence a second series of determinations was made from a piece of land that had a crop grown according to the methods followed by an average Deccan cultivator. The main difference lies in the fact that the cultivator's plot was stirred on a less number of occasions, and had a higher density of plant population, than the specially treated plot and also had some weeds.

The maximum rise in nitrogen contents was nearly the same as on the controlled experimental plots. It was reached in December as in the case of the first series. The chief difference noticed was the sudden fall in nitrogen in one month's period after reaching the maximum and the amount of nitrogen after this fall was comparatively lower than in the former series. At the end of the year's period the nitrogen left in the soil was about 23 per cent lower than that with which the series was started.

The results of the investigation of the second group of plots dealing with three series receiving organic matter added in the form of farm yard manure and green manure or *Crotalaria juncea* may be summarised as follows :—

(1) Nitrogen contents of the soils treated with organic matter showed changes very similar to those observed in untreated soils. (2) The total increase or gain in nitrogen content over the original was, however, much greater in these series than in the series receiving no organic matter. (3) The time of maximum increase was a month or two earlier in the case of addition of farm yard manure or of *sann* in the year of experiment. (4) Where the addition of *sann* was done two years before the experiment the activity and changes in nitrogen contents were very similar to those of unmanured series. (5) There was no substantial difference in the form of nitrates and nitrites except the fact that the maximum peak of nitrate contents was reached later in October or November in cases where additions of organic matter were done freshly. In the case of residual organic matter, the nitrate and nitrite nitrogens behaved exactly as those in the unmanured series.

Definite recuperation of nitrogen takes place in the soils under field conditions in the dry farm tracts of the Bombay Deccan. Wetting of the soil by the monsoon rains and the subsequent partial drying and heating during the dry spells of the monsoon seems to be favourable for starting the recuperation process. Better cultivation of the land helps to maintain the

nitrogen contents of the soil fairly high and does not allow a sudden drop after the maximum peak is reached.

The nitrogen content of the soil is not a stable or a constant quantity. There is a range in every soil depending upon such factors as the moisture, temperature and aeration, which in their turn are dependent upon the climatic factors. Hence the determination of nitrogen contents of a soil without any attention to the time or season of sampling or other concomitants like the moisture and temperature is not likely to throw much light on the fertility of the soil as far as this ingredient is concerned.

IV

The soils on which the above work was done were brought under cultivation only in 1924, before which they were occupied by jungle shrubs. The crop grown on those soils was *Rabi Jowar* (cold season). Further investigation was carried on to find out what fluctuations in soil nitrogen take place under other conditions of climate and soil treatment. Three places were chosen for experiments.

At Poona (rainfall 33·55 inches, 902 mm., 1933) the soil is all from the Deccan trap. One set of experiments was on a soil with a four-month rainy season crop and the other on a soil with an eight-month crop of turmeric under irrigation.

At Belgaum (rainfall 61·6 inches, 1563 mm., 1933) the soil on which the experiments were made was a mixture of material derived from both trap and laterite. On this soil the practice is to grow three crops. The first is a rainy season crop of rice and then there are two others of vegetables grown one after another under irrigation.

At Karjat the soil is derived from trap. The tract receives the heavy rainfall of 154·12 inches (3910 mm., 1933) from June to October. A rainy season crop of rice is grown.

For comparative results both uncropped and cropped plots were studied in each case. Twelve soil samples were taken from each plot every month for 13 months and nitrogen in various forms was determined. Sampling and working errors were ascertained.

Annual cycle of nitrogen fluctuations.—The results obtained show that there are nitrogen fluctuations from month to month and there is an annual cycle of fluctuations for all soils.

Nitrogen and organic matter.—By comparing the total nitrogen figures for uncropped and unmanured plots it is seen that both the highest and the lowest levels of total nitrogen are higher in soils with a large proportion of organic matter than in those with a smaller proportion of organic matter.

TABLE VI.

Relation of organic matter to total nitrogen in soils.

Plots	Organic matter per cent	Per 100 grams of oven dry soil	
		Highest total nitrogen. Milligrams	Lowest total nitrogen. Milligrams
Poona	1·53	51·07	41·22
Karjat	1·81	86·29	81·19
Belgaum	4·44	236·47	197·69

Seasons of highest and lowest levels of nitrogen.—The highest point of total nitrogen reached by a soil may depend on many factors, but in the climatic conditions of the Bombay Deccan the values are high during the cold season between November and February. Although the minimum temperatures in these months are low, they are not so low as to interfere with the reactions of the soil. The maximum temperatures and the moistures in this season, taken together, are favourable for soil reactions. Sometimes another high figure for total nitrogen is obtained in June when the soils heated during summer are wetted by June rains. The total nitrogen is generally low in May when the moisture goes very low. Sometimes very low figures of total nitrogen are found in the middle of the rainy season—July to August—due perhaps to heavy washing.

Seasons of highest and lowest nitric nitrogen.—It was observed that both in the cropped and the uncropped plots nitric nitrogen is high in the cold season when the temperature and moisture taken together form a favourable condition for nitrification. The lowest figures for nitric nitrogen are found in the middle of the rainy season when the nitrates are likely to be washed away. The nitric nitrogen is higher in the uncropped than in the cropped plots.

It was observed in the previous experiments done in connection with the nitrogen recuperation of soils that the cropped rice plot showed more nitrogen than the uncropped rice plot during the growing period of the rice crop. These results have been confirmed by the field experiments in the winter season at Karjat and Ratnagiri and in the rainy season at Karjat.

These results received further confirmation by the experiments done in the laboratory which show that the rice soils have the power of fixing nitrogen and this fixation is helped by the presence of the growing roots of the rice plant. It has been shown that the rice seed does not carry within it any nitrogen fixing organisms.