

NITROGEN AND DRAINAGE

By O. W. M. PEARCE.

Seventy-five to eighty per cent. of the earth's atmosphere consists of nitrogen gas. It is not strange, therefore, that every living thing, both plant and animal, contains nitrogen within its cell-like structure or cells of its body.

The purpose of this paper is to consider very briefly some of the complicated processes taking place in the soil (and some of the variable factors influencing them) that make nitrogen available to plants.

The main sources of nitrogen in the soil which as such are unavailable to the plant are :

- (1) Nitrogen gas found in the soil air.
- (2) Nitrogenous compounds in the dead vegetable matter located in and on the soil.
- (3) Nitrogen compounds in the bodies of soil micro-organisms.

The nitrogen of the three above sources of nitrogen is not available to the plant until it has been converted to ammonia, the nitrites or nitrates. In sugarcane probably the most important of the above three compounds is the nitrate nitrogen form. When added to the soil in a commercial fertilizer, nitrate nitrogen, if applied in fairly large quantities, under certain conditions can also be the most uneconomical type, for it is readily leached from the soil during and after a heavy rain. The result is that very little or any available nitrogen may be left for the nutrition of the plant. In contrast, commercial inorganic nitrogen in the ammonia form is not readily leached from the soil. This form, however, tends to make the soil acid. This disadvantage can be easily overcome by addition of lime to the soil.

Nitrogen, when added to the soil in the ammonia form, is slowly converted to nitrites by nitrosomonas and nitrosococcus bacteria, and, secondly, by nitrobacter bacteria to nitrates, in which form nitrogen is readily taken up by the plant.

The nitrogen gas in the soil air is made available to the plant mainly by two methods. One is through the agency of legumes; the other by the fixing of nitrogen from the gas by bacteria living a free existence in the soil.

The legumes, and the bacteria that are associated with them in the root nodules, by some obscure process are able to fix atmospheric nitrogen from the soil air. This nitrogen eventually is taken into the body of the plant itself, and, according to Waksman and Starkey, "under conditions where legumes make

good growth, there are usually between one hundred and two hundred pounds of nitrogen fixed per acre."¹

Of the amount of nitrogen fixed by legumes when in symbiotic association with legume bacteria about seventy-five per cent. is located in that part of the plant that is above the ground (i.e. the stem and leaves). The quantity of nitrogen found in the root system of the legume that is grown in a soil low in nitrogen is the other twenty-five per cent. This amount represents approximately the quantity of nitrogen that is obtained by the plant from the soil.

It is obvious, therefore, that farmers who grow legumes in order to improve their soils, and who cut and remove the legume crop from the field, or graze animals on the field, are not getting the full benefit of the legume crop as a soil improver.

Most legumes grow best at soil reactions close to neutrality. Lupines, however, will tolerate and put on good growth in fairly acid soils.

In order to ensure that the root system of the legume is adequately supplied with air from which the symbiotic association of the legume and its bacteria is able to fix nitrogen, the soil must be well prepared and, if necessary, drained prior to planting. This is particularly necessary in heavy clay soils which are inclined to be somewhat compact.

As mentioned earlier, the other method by which the nitrogen gas of the soil air is fixed is the method by which certain soil bacteria are able to fix the nitrogen as complex organic and simple inorganic compounds. These bacteria are known as non-symbiotic nitrogen-fixing bacteria, as they are not associated with any higher plant in the fixation process, as, for example, are the bacteria found in the nodules of legumes.

Like all other living things, bacteria of the soil do best on a balanced diet. They also do best when the environmental conditions of their habitat (in this case, the soil) are conducive to their rapid growth.

The question now arises as to what is regarded as a balanced diet for bacteria and what are the environmental conditions best suited for their growth.

As to what constitutes a balanced diet for bacteria, the answer is not known to the writer, and, if it were, it would be far too complex a subject for a paper of this type.

It may be said, however, that if the soil is well supplied with organic matter from which the nitrogen-fixing bacteria are able to obtain carbon

as a source of energy, and if there are adequate supplies of phosphorus and potassium (superphosphate and potash fertilizers) and sufficient calcium (lime) and smaller quantities of other minerals, the nutrient requirements of the bacteria are as well supplied as is possible under practical farming conditions.

The desired environmental conditions are satisfied by having a well-drained soil of good friable structure, and a soil which is neither too acid nor too alkaline. The friable structure of the soil permits easy access of air (which contains the necessary nitrogen gas). The well-drained soil is conducive to the growth of aerobic bacteria, and reduces the degree of denitrification caused by anaerobic bacteria that thrive in conditions lacking oxygen.

The bacterium *Azotobacter* is one of the most important agents by which nitrogen is fixed in the soil. It is very sensitive to soil reaction and soil temperature conditions. Its optimum requirements are:

- (1) A reaction close to neutrality, that is, a pH of 6.0 to 7.6.
- (2) A temperature of approximately 82°F.
- (3) A soil moisture content of about 50 per cent. of the soil's moisture-holding capacity.

Under these conditions strictly controlled in a laboratory, D.S. Byrnside and the writer found that *Azotobacter*, contaminated by *Radiobacter*, fixed as much as a hundred pounds and more nitrogen to the acre. These results, however, are of academic interest only, as all the environmental conditions required by *Azotobacter* are very seldom found in nature at any one given time. Nevertheless the bacterium can and does fix valuable quantities of nitrogen in the soil under field conditions.

Micro-organisms in the soil contain complex nitrogen compounds within their bodies. This nitrogen, as previously stated, is only available to the plant after it has been converted to simpler inorganic nitrogen compounds, such as ammonia and the nitrates which are available to the plant. And also, of minor importance, are the nitrites which are taken up by a few plants.

The conversion of unavailable complex organic nitrogen compounds to the simpler inorganic ammonia compound is accomplished by an involved microbiological process.

One very important factor in this process is the carbon-nitrogen ratio of the organic material involved therein. If the carbon-nitrogen ratio is low, say from 10-30 to 1, the conversion of complex nitrogen forms to the simpler inorganic form is not held up by the carbon-nitrogen ratio factor.

The carbon-nitrogen ratio of many types of microbial cells is from 4-10 to 1; therefore the nitrogen within their bodies is readily converted by other micro-organisms to inorganic ammonia.

On the other hand, if the organic material has a wide carbon-nitrogen ratio and there are large quantities of this type of organic matter in the soil, it will be some considerable time, possibly two or three months, or even longer, before any useful quantities of nitrogen become available to the commercial crop.

Bacteria that decompose organic matter characteristically assimilate about 10 parts of carbon to 1 part of nitrogen. The carbon-nitrogen ratio of the dead leaves of sugarcane is approximately 80-90 to 1. The mechanical inclusion into the soil of this material means that it is going to influence to a great degree the available nitrogen to the following plant crop. The more thoroughly the trash is mixed with the soil, and the greater the quantity added, the less will be the nitrogen immediately available to the crop.

This condition can be improved somewhat by the addition to the soil of commercial inorganic nitrogen fertilizers. In some cases a cane-grower may find it more profitable to get rid of the high carbon-nitrogen ratio material (i.e. the trash) by burning and adding to the soil comparatively low carbon-nitrogen ratio material in the form of a green manure crop. On the other hand, if the soil is already high in organic matter (and such a condition is found characteristically in some of our higher-altitude soils), it may pay to burn off the trash, short-fallow, and add the nitrogen by commercial fertilizers.

Where some of our coastal soils are low in organic matter, this condition should be alleviated by the addition of organic matter with a fairly low carbon-nitrogen ratio. A green manure legume crop with a relatively low carbon-nitrogen ratio of 30-40 to 1 will result in improved soil conditions.

No hard and fast rule can be applied, however; every situation must be treated on its own merits.

Involved with the nitrogen-soil complex is the question of drainage.

A poorly-drained damp soil is usually very acid, and low, or even lacking, in available nitrogen. This nitrogen deficiency is caused to a large extent by anaerobic denitrifying bacteria that exist in the oxygen-deficient environment of boggy soils.

For the growth of profitable crops in soils of this type it is essential to have an efficient drainage system. There are many and various types of drains to be seen in the cane-fields of the Natal Sugar Industry. Some are six inches deep and less, others are of various depths up to fifteen feet and more.

The purpose for which a drain is constructed, that is to be considered here, is that type of drain that will remove as efficiently as possible excess water found in damp spots within the field itself.

A.—The requirements in a drain of this nature are :—

- (1) That it shall remove excess water.
- (2) That it shall interfere as little as possible with agricultural operations within the field itself.
- (3) That it shall cause as little erosion as possible.
- (4) That it shall remove from the soil a minimum of plant foods.
- (5) That it shall improve the crop in the drained area.
- (6) That it shall be economical in construction and maintenance.

The answer to the above requirements in most cases is a deep drain, and, for preference, a French drain four feet deep.

B.—The advantages of a French drain over an open drain are that :—

- (1) It does not interfere with the use of agricultural implements in the field as does an open drain.
- (2) During its useful life it costs nothing to maintain; an open drain does.
- (3) With the same drainage gradient it carries away less soil than an open drain.

Points (1), (2) and (3) in Section B satisfy all the requirements of Section A except for the cost of construction in Point (6).

The construction of a French drain will always be considerably more expensive than an open drain of the same depth. The cost, however, can be modified somewhat by the choice of, and availability of materials.

The types of materials used in the construction of French drains in Natal cane-fields, known to the writer, are bushwood, stones, bamboo and cane trash. Cane trash is used as a "seal" between the overlay of soil and the drainage medium of bushwood, stones or bamboo.

In most cases French drains can be constructed with vertical sides. This feature results in the removal of less earth than in the case of the open drain of the same depth and results in the consequent saving of the cost of earthworks.

The final filling-in of the French drain with the necessary materials does, however, make it more expensive than the deep open drain.

It is not possible to give any costing figures at this stage, but it is felt that the advantages of the French drain over the open drain make it by far the most economical proposition.

The construction of the French drain after the completion of the earthworks is, briefly, as follows:—

- (1) Bushwood, stones, or bamboo are placed in the bottom of the drain to a depth of approximately one foot.
- (2) Loose cane trash, to a vertical cross-section depth of two to three feet, is placed on top of the "percolating" medium, i.e. bushwood, etc. This trash is compressed down to a thickness of approximately six inches within a few weeks by the weight of loose earth placed on top of it.

The net result of this construction is that the drain has one foot of "percolating" medium, a "seal" of six inches of trash, and a final section of two feet six inches of earth.

The vertical section of two feet six inches of earth above the trash permits the efficient operation of all field implements, including the use of the subsoiler.

At this stage it is well to compare the relative merits of shallow open drains from six inches to one foot in depth with those of the French drain.

The shallow drain :—

- (1) Per running foot is cheaper to construct than a French drain.
- (2) Has maintenance costs, whereas the French drain has not.
- (3) Does not remove water from the surface of the soil as quickly as does the deep French drain; therefore, to remove water at an equivalent rate, more shallow drains are needed.
- (4) In operation carries off a high percentage of water from the first six to twelve inches of surface soil. By comparison, the French drain does not.

Points (1) and (2) of the relative merits of the two types of drains are self-explanatory.

With reference to points (3) and (4), the French drain, because of its depth, removes a great deal of the water it carries off from the subsoil area. The reason for this is that the pressure exerted at its base by a column of water four feet high is approximately 1.73 pounds per square inch. In a four-foot drain the effective value of this pressure in the movement of water into the bottom of the drain is modified a great deal by the resistance to the movement of water set up by the type and structure of the subsoil.

Even in a heavy clay subsoil there is a high rate of water seepage into the drain at its base.

The removal of water by the drain at its base results in the lowering of the water table in the surrounding area. The surface water, therefore,

instead of moving in a lateral direction, as it would do in the case of a shallow drain, tends to move in a downward direction.

To summarise, the significant points of the above facts are that :—

- (1) A shallow drain, because it entirely removes a great deal of water from the first six to twelve inches of soil, also removes out of the reach of the plant considerable quantities of plant foods, which include soluble nitrogen.
- (2) In the case of the deep drain, because the surface water tends to move in a downward direction, the plant foods are still available to the deeper-growing roots of the plant.
- (3) Deep drainage or underdrainage increases the soil area accessible to the roots of plants by the removal of free water from the lower regions of the soil. Because of this fact, the effects of drought are reduced.

All the foregoing opinions on field drains are of little value unless they can be substantiated by practical results.

In waterlogged soils in a certain area French drains were made. The result is that the plant-cane now growing in these soils is estimated to cut out in October at the rate of thirty-five to fifty tons per acre. The same soils, which formerly were served by shallow drains or "bed-lines," grew a maximum of ten to fifteen tons of cane per acre in the plant-cane cycle, and considerably less in the ratoon cycle.

It should be mentioned that, prior to the planting of the last crop, a considerable quantity of lime was added to the soil.

(1) Waksman, S.A., and Starkey, R.L. *The Soil and the Microbe*. Chapter V: John Wiley & Sons Inc. New York, 1934.

The PRESIDENT remarked that when the Experiment Station was first opened the cane planter paid little attention to nitrogenous fertilizer, although he had realised the necessity for application of phosphate. This was due to the lack of response obtained from the mixed fertilizer then used, and it was only in recent years, when nitrogen came to be added as a straight fertilizer, that the benefit derived from its application became apparent.

He thought that the author might have mentioned another important source of nitrogen—that obtained directly from the atmosphere and washed into the soil by rain, although the amount available from this source had been perhaps exaggerated in certain papers presented to this Congress in previous years.

Commenting on the remark about the removal of portions of legume green manure crops from the field, he pointed out that green manures had been found

to benefit the following plant cane crop, but very seldom the ratoons, even though the nitrogen supplied by the green crop was more than necessary for the plant cane. It appeared that there was some loss of nitrogen therefore, possibly by leaching, and some of this could be saved by removing the surface crop for animal feed or composting. While lupines were excellent for fairly acid and poor soils, they appeared to require winter rains, and were not suited to Natal conditions.

On the question of drainage, which was very important in ordinary cultivation, but especially so where irrigation was carried out, it had been found that in heavy clay soils, with underlying stiff shale, French drains sooner or later became clogged.

Mr. PEARCE said that as much as 20 lbs. per acre of nitrogen had been found to be fixed within the atmosphere and brought down into the soil by rain, at Rothamstead the figure being 8 to 10 lbs. per annum. The reason for some of the nitrogen made available by legumes being lost was that it was changed from the unavailable form in the plant to the nitrate form quicker than the cane could take it up. There was thus a temporary excess which could be lost by leaching.

Mr. STEYN drew attention to the experience on the South Coast, where, on trashing cane, the ratoons had been found to deteriorate so much that burning of cane had been again resorted to.

Mr. PEARCE mentioned that many had found that ratoons of trashed cane sometimes did not shoot up well and were stunted and yellow. Pot experiments at the Experiment Station had shown similar results. This indicated the possibility of shortage of nitrogen within the soil. The explanation suggested by Dr. McMARTIN was the carrying down of soluble carbohydrates contained in the trash. This resulted in the micro-organisms, which used the carbon as a source of energy, locking up the nitrogen in the soil so as to maintain within themselves a very low carbon-nitrogen ratio.

Dr. MCMARTIN had heard it stated that the coastal soils had no azotobacter. On two occasions, however, he had found it to be present, and he thought that if it were not found, that might be due to soil conditions being unsuitable for its development. Sir A. D. Hall had suggested that, in tropical countries like Africa, azotobacter could take the place of the legume bacteria of Europe. We might, therefore, help ourselves more by maintaining the organic content of the soil, rather than by growing legumes for their nitrogen-fixing bacteria.

The bad effect of trash lying on the soil could be much exaggerated, and it was noticeable mostly in the colder months. Canes growing with trash lying on the soil grew much better than those which

had trash mixed with the soil, and this suggested denitrification. Mr. du Toit had found that canes grown with trash lying on the soil were suffering from nitrogen starvation, and the suggestion was therefore made that carbohydrates were being washed down into the soil from the trash.

Mr. PEARCE said that in connection with azotobacter and soil conditions, he had found that the optimum pH for its development was about 7.6, which under practical conditions was very high. He had been astounded to find a pH of as low as 4.1 in hillside soils which had grown cane for many years. Under such conditions one could not expect any fixation of nitrogen by azotobacter, but it could do good work at a pH of 6.6.

The PRESIDENT described results obtained in a field experiment at the experimental farm at Chaka's Kraal. In this experiment, for the first few months, first ratoons in plots covered with trash were very backward as compared with those of burnt plots. However, a remarkable difference was in evidence later, and there was every indication that the trashed cane would give a much better ultimate yield than the burnt cane. It seemed that where there was much difficulty in getting ratoons to germinate after trashing, this might be due to lack of air and excessive moisture. In that case it might be best to relieve the trash so as to make narrow channels for air and for the new shoots to grow in.

Dr. DICK considered that probably under dry conditions a blanket of trash was of benefit in preventing evaporation, whereas under very wet conditions it might keep the soil too wet and lead to denitrification.

Mr. PEARCE described conditions in a field of fairly light soil from which cane was cut in August two years previously. The yield was 30 tons per acre and the resulting trash was left undisturbed on the soil. It was afterwards top-dressed with 400 lbs. of "H" mixture of fertilizer which was broadcast as evenly as possible by hand over the trash. It was remarkable now to see the porosity of the soil, due to the animal life beneath the trash. The estimated yield of cane from that field at present was 35 tons per acre.

There was another field, too, in which the same system had been applied. In this case the soil was heavier, but the results of the treatment were similar. With the present drought, the soil was hard, yet still very porous, and when the rain did come it would go easily into the soil, taking with it the necessary air for the action of aerobic nitrogen-fixing bacteria. There would be no run-off unless there were exceptionally heavy rain.

Mr. DU TOIT thought that when referring to acid soils Mr. Pearce had the higher altitude soils in mind. Some of these were rather acid, and the action of azotobacter might be small. However, these soils were probably the least responsive to nitrogen applications, and had been limed without beneficial result.

He agreed that leaving a blanket of trash had led to the improvement of soil conditions in a number of places, but he felt that not enough was known to justify this as a general practice. Mr. Steyn had shown the opposite side of the picture, and Dr. McMartin had mentioned some cane that grew very slowly and looked yellow when grown under a layer of trash. The cause of this was still unknown, although in a small pot experiment at the Experiment Station nitrogen was found to be lower in the pots where trash was left on the soil than it was in those free from trash. The chemist could play a very important part in determining the explanation of results obtained in trashing experiments carried out in different localities.

Dr. BATES said that it was only in recent years that it had been realised that improvement in soil conditions could be due to the flora of the soil. This suggested that at present we were dealing with a lot of surmises. He thought that not only was microbiological examination desirable, but it would also be interesting to know the soil microbiological population at different levels, as well as the distribution of the cane roots at these levels in relation to the availability of plant foods.

With regard to trashing of cane, he remarked that under the very arid conditions in Rhodesia, trashing was done largely with the idea of conserving moisture. With certain varieties, particularly Co.281, when trash was left as a general cover over the cane lines, very erratic germination of ratoons resulted. Average growth was better, and far more uniform, where the trash was placed between the lines. He doubted that this was due entirely to a chemical factor and thought the possibility of a disease factor should be considered.

Mr. RAULT stated that while there were controversial views on the use of molasses as a fertilizer, in other countries it was used extensively. While it supplied an enormous amount of carbohydrate, it also supplied potash and it was known that the residue from distilleries had a beneficial effect. He enquired if there was any local experience in the application of molasses to the soil.

The PRESIDENT said that molasses had been tried as a fertilizer at the Experiment Station with negative results either for or against. In Australia he had seen a very striking experiment. A particular soil had been found no longer to tolerate a certain

variety of cane. This condition had been rectified by sterilising the soil in various ways. One way was to apply molasses. The first result of fermentation of the molasses was to sterilize the soil. This effect of the fermentation products would pass off and they would change into other substances, leaving the soil a virgin field for new bacteria, and giving it, in many cases, a new lease of life.

Mr. DU TOIT mentioned that interesting work had been done in Queensland on the use of molasses, and he had seen photographs illustrating the increased microbiological activity in the soil which had much improved its condition, and which had followed the application of molasses.

Dr. McMARTIN described soil tests with Co.281 carried out at the Experiment Station two years previously. The greatest weakness of Co.281 was its susceptibility to root diseases. In these pot tests Co.281 was planted in a soil, some of which was partially steam-sterilised, some treated with molasses equivalent to about 4 tons per acre, and some was untreated. The cane planted in the untreated soil grew rather poorly, but there was a marked improvement in both the partially steam-sterilized and the molasses-treated soil, with no obvious difference between these two.

Mr. PHIPSON enquired if the molasses was diluted before application to the soil.

Dr. McMARTIN replied that in the test he had described the molasses was put on undiluted. A different

type of micro-biological growth followed the application of diluted molasses, compared with that which resulted from the concentrated molasses. This was shown by experiments in Mauritius, where it was claimed that a result was obtained with diluted molasses different from that which resulted from the use of undiluted molasses.

Mr. DU TOIT stated that two semi-chemical experiments had been carried out at the Experiment Station, using soil treated with molasses and mercuric chloride. In both cases cane growth was much better in soil so treated as against the untreated soil.

Mr. BEATER pointed out that concentrated molasses had been used, but the soil was watered shortly afterwards.

Mr. DU TOIT considered that a very interesting point about the work done in Queensland was the fact that the soil structure was much improved by molasses.

Mr. ELYSEE enquired if the pH of the soil was affected by molasses, because of the formation of acids on fermentation. At a small factory in Zululand the molasses had to be discharged on to a field in dilute form. There was no growth at all of cane where the molasses was discharged.

Mr. BEATER replied that no effect on the pH of the soil had been found in the experiments previously described.