THE NITROGEN STATUS OF THE SOILS OF BURMA.

By S. P. Aiyar, *B.A., Ph.D. (Lond.), A.I.C., Agricultural College, Mandalay, Burma.*

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

Introductory.

The association of nitrogen with the organic matter of the soil is so intimate that it is usual to consider a soil rich in organic matter to be also rich in nitrogen.

Soil organic matter arises from the decomposition of plant and animal residues falling on the soil. The subject has been illuminated notably by the researches of Remezov [1933] in Russia and of Waksman and his co-workers in U.S.A. The various factors which determine the character of the equilibrium product, soil organic matter, have been discussed by Waksman and Starkey [1931] and by Waksman [1936, p. 62]. Our knowledge of the organic matter of the tropics is meagre. The general principles of decomposition of organic matter may be the same in the tropics as in temperate regions. But in contrast with the temperate regions, the largest crop in the tropics is rice which is cultivated under water-logged or partially anaerobic conditions. Sufficient is known, however, to indicate that the changes which organic materials undergo in water-logged conditions are different from those under aerobic conditions.

The conditions regulating the humus content of soils in the tropics were stated by Mohr [1929] and later experimentally verified by Senstius [1930]. According to Mohr humus can accumulate only at temperatures below 25°C. in a properly aerated soil. Under water-logged conditions, however, humus can accumulate until a temperature of about 35°C. is exceeded. Jenny [1932] has also formulated a law according to which the nitrogen and organic matter content of a soil are shown to be functions of the temperature and humidity. The nitrogen content of the soil decreases exponentially with temperature. One may therefore expect low nitrogen figures for tropical soils. According to Jenny's law, the nitrogen content increases logarithmically with increasing humidity if the temperature remained constant. The advantage of a high humidity factor is however rendered negligible as temperature seems to control the nitrogen to a much greater extent. However, Jenny's law applies only to aerobic conditions. Water-logged conditions tend to accumulate organic matter as well as nitrogen, because under these conditions the microflora seem to be able to work with a much smaller amount of nitrogen than that required by them under aerobic conditions.

VOL. III—No. 2. [Published April 28th, 1937.

The Soils of Burma.

The soil receives raw organic material from the vegetation growing on it. The vegetation in turn depends on the climatic and other factors concerned, namely, rainfall, temperature, altitude, drainage, soil reaction, soil texture and so on. The first three are regional factors. So far as Burma is concerned the mean temperatures are almost uniformly high, except in the Shan Plateau where the altitude of 3,000 feet keeps down the mean temperature by several degrees. The rainfall distribution varies widely and seems to control the nature of the vegetation. Stamp and French (1929) have classified the vegetation of Burma on the basis of rainfall and altitude. The chief divisions are :—

1. The Dry Zone : Rainfall 40 in. or less. Small trees and shrubs form the natural vegetation. Cotton, millets, jowar, maize, peas and beans grow readily. Rice and sugar-cane can be grown but require irrigation. The toddy palm grows well.
2. The Region of the Monsoon Forest. The rainfall exceeds 40 in. but does not exceed 80 in. The trees are deciduous and include teak, pyinkado and other hard woods, as well as the bamboo. A great deal of the area is covered by forest but sugar-cane, rice, sesamum, tobacco and other crops are extensively grown.
3. The Delta Region or Region of Mangrove Forest. The rainfall ranges from 80 to 120 inches. Most of the land is liable to floods and marshy conditions prevail during the rains. The area near the sea and creeks carry mangrove forest cover but a very high proportion of the area is devoted to rice cultivation.
4. The Region of Evergreen Forest. The rainfall ranges from 100 to 225 inches. The trees are green throughout the year, they are often of very large size and their wood is very hard. The area is too wet for teak and pyinkado. Most of the lowlying land is cultivated. Rice is the chief crop. Rubber and mangosteens are grown on upland soils. Cocoanut palms are important near the sea.
5. The Shan Plateau. The altitude is about 3,000 feet or more. The rainfall varies from 50 to 60 inches. The soil is a red loam derived from dolomitic limestone and other hard rocks. On the hills there are evergreen forests consisting of oaks and pines. On flat or rolling land grass is the chief vegetation. Rice is cultivated in the valleys but the area is well suited for the growth of coffee, tung oil tree, oranges, pears and other fruits, vegetables and a large variety of flowers. In contrast to most of the soils of the alluvial plains of the lowlands which are generally badly drained, the soils of the Shan Plateau are well drained except perhaps in the valleys.

A general account [Aiyar, 1936] of the agriculturally important soils of Burma has been published recently. Detailed surveys have been published for the most important rice areas in Burma [Charlton, 1931 (*a*), 1931 (*b*)] as well as for sugar-cane [Charlton, 1935]. An important monograph on the vegetation and soils of a large monsoon forest area is also available [Barrington, 1931]. Besides these, the reports of the agricultural farms, the season and crop reports, the Gazetteer of Burma, and the Atlas of Burma are useful sources of information.

The Nitrogen Content of the Soils of Burma (Table I).

Since the humus and nitrogen contents of a soil depend upon the vegetation the soils are grouped below on the basis of the vegetation groups. The rainfall and the pH values are also tabulated. The pH is a useful guide as it may indicate whether a soil contains appreciable amounts of lime or whether the soil is so acid as to suppress the bacteria and encourage the fungi. The texture of the soil may be expected to modify the rate of humus formation by regulating drainage and aeration. The value of the texture is stated in terms of the sum of the percentages of clay and silt (Atterberg) or of clay and fine silt (British). Although there are objections to this method, it is probably as good as any other.

TABLE I.

The Nitrogen Contents of the Soils of Burma

Locality	Crops	Rain-fall in inches	pH	C%	N%	Texture
		The Dry Zone				
Kanbalu Farm ..	Dry crops ..	40	6·1	·80	·07	35
,, ..	Paddy ..	40	6·4	·50	·04	29
Chiba Farm (irrigated)	,, ..	36	6·1	·39	·05	32
,, ..	,, ..	36	6·6	·25	·04	31
Padu Farm. Black soil (Marshy) ..	Dry crops ..	32	7·9	·49	·05	78
Padu Farm. Red soil (on slope) ..	,, ..	32	6·1	·23	·04	13
Nabehla-Shwebo ..	Paddy ..	30	8·0	·25	·04	92
Mandalay Farm ..	Dry crops ..	30	8·1	·40	·03	57
,, (irrigated)	Paddy ..	30	8·1	·42	·04	56
Singaing—Bad drainage	Sugarcane ..	30	7·3	·92	·13	67
Meiktila Forest ..	Trees ..	30	7·3	·92	·03	4
Mahlaing Farm ..	Cotton ..	33	7·7	·41	·06	8
Allanmyo Farm ..	Dry crops ..	46	5·9	·82	·09	46
Tatkon Farm ..	,, ..	40	7·0	·55	·08	18
Pyawbwe ..	,, ..	32	7·8	·54	·06	43
Pwinbyu Farm ..	Sugarcane ..	35	7·3	·74	·13	68
Mean value ..		**35**	**7·1**	**·54**	**·06**	**44**

Locality	Crops	Rain-fall in inches	pH	C%	N%	Texture
The Monsoon Forest Region						
Sahmaw Estate ..	Virgin land Grass.	95	6·7	3·59	·29	45
,, (high land)	Sugarcane ..	95	6·4	1·92	·12	46
,, (medium)	,, ..	95	6·3	2·33	·16	25
,, (low, bad drainage)	,, ..	95	6·2	3·04	·21	32
Hopin (high land) ..	,, ..	90	6·6	·75	·08	23
,, (low land) ..	,, ..	90	6·5	·91	·08	31
Mawkin—Myitkyina Dist.	,, ..	80	4·8	2·28	·16	69
Namti ,, ..	,, ..	90	5·0	2·67	·19	47
Kondan ,, ..	,, ..	90	6·2	0·31	·03	12
Namkwin ,, ..	,, ..	90	5·7	1·39	·10	31
Mawhan—Myitkyina Dist.	,, ..	90	4·2	1·65	·18	57
Katha—Katha Dist. ..	,, ..	60	5·6	1·03	·09	33
Naba— ,, ..	,, ..	70	5·2	1·07	·11	25
Pyinmana Farm—highest land	,, ..	56	6·5	·57	·07	32
,, lowest land	,, ..	56	6·5	·74	·06	25
Monhit—Pyinmana ..	Forest ..	56	6·9	·99	·06	12
Thayagon ..	Sugarcane ..	56	5·9	·86	·07	43
Thabyehla ..	,, ..	56	5·1	·57	·06	27
Kanyutkwin ..	,, ..	90	5·8	1·60	·13	89
Linyawkin ..	,, ..	90	5·1	·67	·07	36
Lebyingyi ..	,, ..	90	5·9	·73	·07	35
Mean value ..		80	5·9	1·41	·11	37
The Delta Region						
Tonkan Forest Reserve	Forest ..	120	6·3	·89	·09	29
Magyipin Village ..	Paddy ..	120	6·1	1·02	·11	60
Seyokin—Grazing ground	Grass ..	120	6·1	·69	·05	9
Pauktaw ..	Paddy ..	120	5·9	1·56	·14	74
Pyuntaza ..	,, ..	120	6·3	1·07	·11	53
,, Reserved Forest	Trees ..	120	5·7	2·40	·20	75
Saze Village ..	Tobacco ..	120	6·1	1·00	·09	43
Thongwa—Flooded land	.. ..	120	5·9	1·23	·09	32
Kadok ..	Paddy ..	120	5·6	3·00	·24	78
Pyinbongyi ..	,, ..	120	5·2	1·10	·10	27
,, Grazing ground	Grass ..	120	5·4	1·56	·14	57
Okpo ..	Paddy ..	120	5·9	·94	·10	44
Kyaikhla—Flooded ..	,, ..	120	5·5	1·17	·09	30
Minywa ..	,, ..	120	5·7	·74	·07	25
Thanatpin—Flooded ..	,, ..	120	5·7	1·34	·13	65
Kyauktan— ,, ..	,, ..	120	5·7	·82	·07	47
Hmawbi Farm—Marshy	,, ..	96	5·6	·98	·10	85
,, Grazing ground	Grass ..	96	5·6	1·79	·16	74
,, Virgin Laterite	,, ..	96	5·1	·59	·07	24
Myaungmya Farm—High land	Paddy ..	99	5·3	1·86	·15	66
,, Low land ..	,, ..	99	5·5	2·23	·17	59
,, Garden soil	? ..	99	5·6	·79	·05	14
Mean value ..		114	5·7	1·28	·11	49

Locality	Crops	Rain-fall in inches	pH	C%	N%	Texture
The Evergreen Forest Regions						
Akyab Farm ..	Paddy ..	225	6·5	·64	·07	20
Mingan Farm (Akyab)	,, ..	225	5·4	1·13	·09	56
Kyaukpyu Farm— Heavy	,, ..	180	5·2	1·12	·10	42
,, Light ..	Cocoanut ..	180	5·6	·57	·05	13
Thaton—Garden soil ..	Mangosteen	217	6·1	3·05	·23	60
Mudon— ,, ..	,, ..	200	5·3	5·46	·30	61
Mudon Farm— Upland soil	Fruits ..	200	5·3	3·30	·15	60
,, Low land ..	Paddy ..	200	5·5	1·86	·14	50
Tavoy—Garden soil ..	Mangosteen	225	5·8	1·49	·13	89
Tenasserim—Plantation	Rubber ..	215	5·3	2·16	·15	26
Bilin—Plantation ..	,, ..	200	5·7	3·65	·24	52
,, ..	Sugarcane ..	200	4·2	2·24	·20	81
Hninpale ..	,, ..	200	4·3	1·01	·16	77
Shwegun (bank of Salween R) ..	,, ..	150 ?	7·1	·78	·08	34
Mean value ..		200	5·5	2·03	·15	52
The Soils of the Shan Plateau						
Yawnghwe Farm— Highest land	Wheat, Potatoes, Oranges ..	45	7·1	1·04	·09	36
,, Intermediate	,, ..	45	6·7	1·34	·12	47
,, Lowest ..	,, ..	45	7·9	1·90	·17	60
Heho (Valley)— Heavy soil	Paddy ..	60	8·0	5·20	·50	47
,, Red soil ..	? ..	60	6·3	1·65	·09	42
,, Yellow soil	? ..	60	5·8	·46	·11	42
Maymyo Forest Reserve ..	Trees ..	55	6·1	2·76	·10	60
,, (From Sylviculturist) ..	,, ..	55	6·6	2·54	·16	14
Taunggyi Farm ..	Wheat, Potatoes, Oranges ..	60	6·1	1·76	·14	59
Mean value ..		54	6·6	2·07	·16	45

N.B.—The data in the Tables refer to the surface soils.

TABLE II.

Mean Values of Nitrogen and Associated factors

Area	Rainfall	pH	C%	N%	Texture
1. The Dry Zone	35	7·1	·54	·06	44
2. The Monsoon Forest Region . .	80	5·9	1·41	·11	37
3. The Delta Region	114	5·7	1·28	·11	49
4. The Evergreen Forest Region . .	200	5·5	2·03	·15	52
5. The Shan Plateau	54	6·6	2·07	·16	45

General Remarks on the data.

The following facts are revealed by the data presented in Tables I and II :—

1. The mean nitrogen content increases with increasing rainfall [Jenny, 1932]. The slight divergence shown by the figure for the Delta Region can be explained by the fact that this area has been under cultivation for long periods.

2. The effect of temperature on nitrogen content is brought out by the striking difference between the figures for the Monsoon Forest Region and those for the Shan Plateau. The increased nitrogen content of the latter is determined by the altitude of the Plateau which ensures a lower mean temperature in this area than in the Monsoon Forest Region. Again, the nitrogen and organic matter contents of the Plateau soils are almost identical with those of the soils of the Evergreen Forest Region. Assuming a mean temperature of 22°C. for the Plateau and 28°C. for the Evergreen Forest Region, the large difference in rainfall is counterbalanced by the small difference in temperature. This fact also is in accordance with Jenny's law.

3. It has been stated by Mohr [1929], Vageler [1933] and others that the effect of water-logging a soil is to increase its organic matter and nitrogen contents. The data for the soils of Sahmaw, Pyinmana, Yawnghwe, and Myaungmya support the above view. The large organic deposits stated to occur in various parts of the tropics most probably arose under water-logged conditions.

4. The nature of the vegetation cover also has a great effect on the quantity of organic matter and nitrogen accumulated in the soil. A comparison of the data for the same place under different kinds of vegetation supports the above statement, e.g. forest, grazing land, and paddy or legumes and paddy at Kanbalu, Pyuntaza, Mudon, Bilin. The effect of cultivation in reducing the organic matter of the soil may also be inferred from the same data.

5. The texture of a soil controls the drainage and aeration. A heavy textured soil may therefore be expected to accumulate organic matter and nitrogen to a greater extent than a light textured soil. However, the mean values in Table II do not support this view, although individual comparisons from the

data in Table I seem to support it. This uncertainty is to some extent created by the manner of evaluating the texture adopted here. A value of 50 for the texture might be made up of a high proportion of clay with a little silt or the reverse. When the clay is high the drainage is much poorer than when silt is high. Apart from this, there is another point that deserves mention here. The physical properties of the clay contained in soils developed in the Dry Zone, in the Evergreen Forest Region and in the Shan Plateau would be different in all probability owing to the different climatic factors involved. The silica-sesquioxide ratio, the base exchange capacity, the lime requirement, may all give some indication of the properties of the soil clay. Even under apparently similar climatic conditions different kinds of clay, e.g. kaolin, halloysite, montmorillonite, may be produced by differences in geological parent material. Several soils of Malaya (from rubber estates) showed high percentages of clay (50 to 80 per cent) but the base exchange capacity at pH 7 seldom exceeded 10 milliequivalents per cent [Albareda]. The clays were white or only slightly brown. The probability is that these Malayan clays are mostly made up of kaolin or allied substances. The clay obtained in a mechanical analysis obviously cannot serve as a guide to the physical properties of the soil unless climatically and geologically similar areas are being considered. It would seem to be desirable to determine some suitable property of the clay in question and convert the percentage of clay by multiplying with a factor into a new value which could help in comparing the physical properties of soils generally. The silica-sesquioxide ratio may be useful but it is laborious to determine and there are also other objections which need not be discussed here.

The availability of nitrogen.

The humus present in the soil is the source of nitrogen for all crops except legumes which can utilise the nitrogen of the atmosphere. The availability of nitrogen is controlled by the decomposition of humus. The factors controlling the decomposition of humus are discussed by Waksman [1936 (*b*)].

The response of crops to nitrogen manuring in Burma [Watson, 1933].

The only certain method of finding out whether a soil can supply enough nitrogen for satisfactory yields of crops is to test the matter by pot and field experiments.

Paddy is the only crop that is grown throughout the country irrespective of soil and climate and the manuring of paddy has received the most attention. Of the other crops cotton and groundnut are almost confined to the Dry Zone ; sugarcane and sesamum are chiefly grown in the Monsoon Forest Region although they are cultivated to some extent in the Dry Zone.

The experiments on paddy will be considered first. The work started in 1912 at Hmawbi in the Delta and at Mandalay in the Dry Zone. Subsequently other stations were established and the experiments repeated, extended or modified.

The Dry Zone.—Mandalay is the chief station for paddy experiments in this area. Cattle manure, oil-cakes and sulphate of ammonia gave the largest increases in yield. Green manures and other organics have also proved excellent. Of the various synthetics, calcium cyanamide, sodium nitrate, urea, and ammonium bicarbonate have been tried and found to give low or no response. In combination with superphosphate ammonium sulphate is more effective than when they are used separately. The addition of potassium sulphate along with ammonium sulphate and super has shown no effect. Other experiments with the mixed fertilisers Leunophos, Ammophos and Nicifos showed that these are as good as a mixture of ammonium sulphate and super of similar composition.

In pot experiments Warth [1916] obtained large increases in yield of paddy by manuring with ammonium sulphate the soils of Mandalay, Tatkon, Pwinbyu, Padu and Kyaukse, all from the Dry Zone. Of these Mandalay, Padu (Black) and Kyaukse soils gave further large responses in yield when phosphate was given along with the ammonium sulphate.

A survey of the Mandalay Canal area (about 145,000 acres of irrigated paddy land) was conducted by the Agricultural Chemist. The nitrogen percentages showed only a low correlation with the yields reported [Charlton, 1931].

The Monsoon Forest Region.

Although paddy is widely grown in this region no manuring experiments have been conducted. In Warth's bulletin there is the record of a pot experiment with soil from Hopin. This soil contained 0·11 per cent of total nitrogen. In agreement with this the unmanured soil gave a high yield of paddy, in fact the highest of all the soils tried. Curiously, however, this soil also responded to ammonium sulphate to an extraordinary degree, but the addition of phosphate with the nitrogen did not materially improve the yield. The pH of a sample of soil growing paddy taken at a later date from the same place was 5·4. The conditions are said to be marshy.

The Delta Region.

Hmawbi and Myaungmya are the chief experimental stations. This is the most important paddy area. The experiments conducted at Mandalay have been duplicated at Hmawbi and in general the conclusions arrived at are the same. The response to ammonium sulphate has been higher than in Mandalay. While phosphate alone or in combination with ammonia has given good increases, potash seems to give negligible effects alone or in combination. The pot tests of Warth with Hmawbi soil showed large increases in yield of paddy by manuring with ammonium sulphate alone or in combination with super. In a further series of tests with the soils of the Delta, Warth and

Po Shin [1919] found that the phosphates applied as manure were effectively utilised by paddy only when ammonium sulphate was also given in addition.

A soil survey of the Pegu District [Charlton, 1931 (*b*)] (about 1 million acres) showed that there was a significant correlation between the nitrogen content of soils and the yields of paddy.

The experiments at Myaungmya have shown that large increases in paddy are obtainable by the use of Ammophos, Nicifos and similar combinations.

The Evergreen Forest Region.

Akyab and Mudon are the principal experimental Stations. Paddy is grown throughout the region wherever the land is relatively flat. At Akyab farm Leunophos gave a maximum increase of paddy with an application of 300 lb. per acre and the yield started decreasing with higher doses. At Mingan, a substation of Akyab, the increases obtained with Leunophos were of the same order as at Akyab. At Mudon the experiments were more numerous. Nicifos, Diammophos, and Leunophos gave moderate increases in yield of paddy. In combination with potassium sulphate Leunophos did not give any appreciable increases in yield over that obtained with Leunophos alone.

The Shan Plateau.

Paddy is grown chiefly in the valleys but no manuring experiments have been carried out there.

The chief facts observed in the manuring of paddy in the various areas are (1) that a good or moderate increase in yield is obtained throughout by the use of ammonium sulphate; (2) that phosphate in combination with ammonium sulphate is generally more advantageous than with ammonium sulphate alone ; (3) the use of potash either alone or in combination has been of no value ; (4) Organic manures always give satisfactory increases in yield.

These observations call for comment. Although paddy has a preference for ammonia as opposed to nitrate it is not clear why the use of ammonium bicarbonate does not produce the same effect as the sulphate. Urea and calcium cyanamide are also similar to the bicarbonate. On the other hand green manures and other organics ploughed into the paddy field liberate ammonia rapidly [Subrahmanyan, 1927 ; Joachim and Kandiah, 1929] and large increases in yield of paddy have been obtained in most places. Ammonium sulphate and the organic manures therefore seem to supply some substance or substances required by paddy which the other synthetics do not contain. The obvious substance would seem to be sulphur. It has been shown that the protein sulphur metabolism is related to the ammonia—nitrogen present [Heiserich, 1935]. Another possibility is that the ammonium sulphate and the organic materials liberate some element from the soil, e.g. iron which the other compounds are unable to do.

Another striking fact is the failure of potash to improve the yield of paddy. In general it is known that the assimilation of nitrate nitrogen is dependant upon an adequate supply of potash. This may have something to do with the charge on the potassium and nitrate ions. With paddy, however, since ammonium ions are used instead of nitrate, there may be antagonism between the two positive ions. The same fact has been reported from Malaya, British Guiana, Italy and elsewhere. On the other hand, potash is always used in Spain, Hawaii and Japan which produce large yields of rice per acre.

Again there seems to be some limiting factor at work in all tropical paddy growing areas. The large increases in yield obtained in cold countries [Montesoro, 1929] by increasing doses of nitrogen can nowhere be approached in the tropics. There seems to exist a bar beyond which the yield of paddy cannot be pushed whatever be the treatment so far tried. This bar appears to be at about 3,000 lbs. per acre in Burma. The existence of such a bar in Malaya has been pointed out by Belgrave in his Reports on Paddy Manuring [Belgrave, 1934]. It has been stated that the maximum yield of rice is greater towards the northern limit of cultivation due to climatic factors [Copeland, 1924]. But there are well-authenticated spots in Burma and elsewhere in the tropics where the yields are far above the 3,000 lbs. limit. A great deal of confusion exists, however, owing to the failure to test the same high yielding paddy in all the different climatic areas in each country.

In spite of the high nitrogen and organic matter contents of the soils of colder countries like Italy, Spain, Japan and U.S.A. large applications of nitrogen have been found profitable in them in paddy cultivation.

Other crops.

The experiments in Burma have not been extensive with other crops. The manuring of sugarcane at Pyinmana has shown that ammonium sulphate is more effective than nitrate and that neither potash nor phosphate appears to be necessary.

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