THE NUTRIENT STATUS AND CULTIVATION PRACTICES OF THE SOILS OF THE NORTH-WEST WHEAT BELT OF NEW SOUTH WALES

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Summary

A study has been made of the nitrogen, organic carbon, phosphate, and pH levels of the wheat soils of north-western New South Wales, and the cultivation practices adopted.

They are found generally to be high in both total and available phosphate, and particularly high figures for available phosphate, over 1000 p.p.m., were found in limited areas.

The nitrogen levels of the virgin chernozemic soils are distinctly higher than those of the red-brown earths and red solodic soils, but soils of all groups show a decline with cultivation, which is most rapid in the first 10 years. The introduction of periods under lucerne raises the nitrogen level, but the wheat/grazed fallow or wheat/grazing oats appear to cause the same nitrogen losses as are encountered under continuous wheat, in spite of the prevalence of stubble burning which inevitably accompanies this practice.

The average yields of wheat on the chernozemic soils are distinctly higher than those obtained on the red-brown earths and red solodic soils, on some of which nitrogen appears to be limiting.

I. INTRODUCTION

As a result of a widespread opinion that there had been a decline in the quality of wheat grown in New South Wales, studies were initiated in 1948 with the object of obtaining a picture of the fertility levels of the main soil types on which wheat is grown, and to assess the effect of the different cultivation practices on them, with particular reference to the nitrogen economy.

Because of the wide variation of soil and climatic conditions encountered it was decided to take samples from 1000 sites distributed throughout the wheat belt, the distribution being determined by the relative intensity of wheat production, taking shire boundaries as a basis and calculating from figures for acreages sown to wheat in the year 1944-45. This figure was suggested as most satisfactory by the Chairman of the Australian Wheat Board, and agreed closely with the figures made available by the Mortgage Bank Department of the Commonwealth Bank.

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In the first instance, work has been confined to the north-west wheat belt, since this includes the youngest wheat areas of the State and in general is at present growing the highest quality wheat.

Adopting 1000 sampling sites for the State as a whole, the shires of the New England and Namoi Regions, which contain the north-west wheat belt, would require to be sampled as shown:

New England Region		Namoi Region			
Shire	Sites	Shire	Sites	Shire	Sites
Bingara	5	Liverpool Plains	40	Boolooroo	8
Ashford	4	Namoi	35	Cockburn	7
MacIntyre	18	Peel	29	Barraba	2
Yallaroi	13	Mandowa	10	Nundle	2
		Tamarang	9		

To obtain a range of comparative treatments on any one property, it was found necessary to increase these numbers although roughly keeping the same proportions. Finally 271 sites were sampled, drawn from 80 properties, and from each at the same time an account was obtained from the farmer of his farming practices, of the cropping and cultivation history of each site, and his opinion of the effect of cropping on the yield and quality of his wheat. Where possible samples were taken from virgin sites and from sites on similar soil type but with varying agronomic history.

II. Sampling Procedure

Although the profile at each site was examined, generally to a depth of 6 ft, to characterize the soil group, the samples taken for the fertility work were confined to the surface soil only, since this supplied the major proportion of the soil nitrogen and would be most markedly affected by cultivation practices. Because of the great variability of surface soils, three replicated samples were obtained from each site, each replicate being made up of 27 samples drawn on a grid across the area concerned. The procedure was as follows: the paddock or area to be sampled was roughly divided by eye into nine equal parts, and from each part nine samples were taken, three lots of three replicaes *a*, *b*, and *c* being taken at random within the area concerned. All the *a* samples from the whole paddock were bulked, bagged, and kept separately from all the *b* samples, which similarly were kept from all the *c* samples. The *a*, *b*, and *c* samples were analysed separately. The samples were taken to 6 in. throughout. Using this procedure the standard error on the mean figure for the nitrogen content is about 3 per cent.

The farms to be sampled were selected after discussion with the District Agricultural Officer after consideration of both the soil type and the occupier. The criteria used were that the soil should be typical of the locality, that the farmer was known to be cooperative and to have kept good records, and that where possible the farm had been in the hands of one family since it was first cultivated.

III. Soils

So far as this work is concerned, in the north-west wheat is grown on red-brown earths and red solodic soils*, chernozemic soils, euchrozems,† and the grey-brown solodic soils,* with minor areas on sierozems and solodized solonetz.

The acquisition and utilization of these areas dates from 1840-1850, when the large holdings were settled first. Cattle first, then sheep, were run over the partly cleared country. Wheat growing started about 1870 in the Tamworth area and spread gradually north and west until in about 1890-1900 some was grown throughout the whole of the present wheat belt. Until about 20-25 years ago the soils used for wheat growing were almost entirely those with the lighter-textured surface soils, that is, the red-brown earths and red solodic soils, whilst the heavy soils were used only for grazing. This differentiation of land use with soil group was due to the extreme difficulty of cultivation along European lines of the heavy "black" soil with the implements then available and the lack of varieties capable of producing grain on those soils. Within the last 25 years, wheat cultivation has spread to these heavier soils, developing earliest on the relatively lighter-textured brown chernozemic soils of the gentle slopes, and only extending in the last 10-15 years to the much heavier black chernozemic soils of the plains. The introduction of more modern machinery, a better understanding of the more rigid cultivation requirements as affecting soil structure and moisture conditions, and the introduction of more suitable varieties have made possible the more widespread use of the chernozemic soils, particularly those of the plains, for wheat growing. A relative fall in the yield from the lighter-textured soils, which have been largely subject to sheet erosion, coupled with the higher yields now generally obtained on the chernozemic soils, is tending to a reversal of the former pattern of land use, with soil group, particularly in the western parts of the area.

IV. The Management Practices Adopted

In a consideration of the effect of management practices on soil fertility, in relation to wheat growing, four aspects are relevant: the crop rotation used, the method of treating the wheat stubble, the cultivation

* These two groups were originally called podsolized red-brown earths and grey-brown podsolic soils by the authors (Gibbons and Hallsworth 1951) but on more recent work have been reclassified as solodic soils (Hallsworth, Costin, and Gibbons 1953).

† Heavy red soils formed partly from laterized basalt (Hallsworth, Colwell, and Gibbons 1953).

practices, and fertilizer treatment. These are clearly not independent, but are largely inter-related. Fertilizer practice varies widely in the different wheat growing regions of the world, and the area concerned here is noteworthy in that, unlike the other wheat areas of southern Australia, little superphosphate is used, and that is restricted to the better rainfall areas of the east.

Such rotations as are practised are extremely variable and in general form no set pattern. Over most of the district, particularly in the northern and western parts, wheat is grown in successive years until such time as the farmer decides the paddock needs a rest, when it is sown to lucerne or oats or allowed to revert to natural pasture. A few farmers have adopted a wheat/long fallow* rotation, whilst one farm only was found which practised a regular rotation of wheat with a long bare fallow, similar to the practice of the central west.

The rotations now generally adopted are:

(1) Wheat continuously, with a short fallow.

(2) Wheat continuously, with a short fallow, but with occasional long spells of lucerne.

(3) Wheat continuously, with short fallow, but with occasional years of oats, long fallow, milo, etc.

(4) Alternate wheat and oats for grazing, or alternate wheat and long fallow.

The stubble may be grazed or burnt, and is sometimes grazed and subsequently burnt. Until recently the almost universal practice was to burn the stubble (left long by the header) and have a short clean fallow, attempting in this way some degree of moisture conservation, or alternatively to graze the stubble as hard as possible with sheep and subsequently to burn and cultivate as convenient. There are three ways in which the stubble may be treated with continuous cropping, namely:

(1) Grazing, cultivating.

(2) Grazing, burning, cultivating.

(3) Burning immediately after harvest, cultivating.

With long fallow the stubble is always sufficiently disintegrated for cultivation and burning is unnecessary.

The original cultivation practices were understandably those of the British Isles, that is, ploughing with a mouldboard plough to 6, 8, or more inches. On most of the chernozemic soils this was not only very difficult

* Some difficulty was met in recording the management practices because of the varying interpretations given to the term "fallow". This was often used in the old English sense of "unused for cropping" but more commonly in the sense of "unused for wheat", which could on occasion even mean sown to grazing oats. In most cases the fallow was grazed until shortly before re-seeding with wheat, and the regularly cultivated fallow, here termed "clean fallow" or "bare fallow", was rarely encountered.

if not impossible with horses, but when accomplished brought to the surface large blocks of soil and exposed large cracks penetrating to depth and allowing rapid moisture loss. On the red-brown earths deep ploughing was possible, but even on these soils the depth of ploughing rapidly decreased and with the advent of the disc plough the mouldboard literally disappeared from the north-west.

Although the climate of the areas concerned is relatively uniform, particularly with regard to the seasonal distribution of the rainfall, there is a marked gradient in annual rainfall, which increases eastwards from 20 in. at Cubbaroi, Mullaley, and Wee Waa on the plains at the west of the wheat area, to 26 in. at Tamworth and 32 in. at Nundle on the slopes at the east of the wheat belt where the land is rising to the Northern Tablelands. This difference in rainfall may have affected the cultivation practices used, for certain differences are found between the farmers of the eastern areas, and those of the plains to the west and north. Some of these are brought out in Table 1, which is a summary of the results obtained in this survey.

The table shows that continuous wheat growing is still generally practised. This is especially so in the western districts around Gunnedah, Boggabri, and Narrabri, where 14 out of 15 farmers still practise it. In the eastern part, other rotations are used, especially the wheat/grazing oats rotation. This difference in practice may be related to the growing opinion of the farmers on the red-brown earths, which predominate in the east, that those soils which had been worked exploitively for a considerable time are now apparently producing poorer returns, and that the obvious and serious soil erosion must be checked.

For the chernozemic soils as a whole, the general picture is similar to that for the red-brown earths as a whole, although as alternative to wheat, grazing oats are less favoured than lucerne. Again there is a difference in rotation practice between the eastern and western parts, with less exploitative rotations in the east and continuous wheat in the west.

The euchrozems around Inverell show no predominant rotation, but differ from the other groups in that special three- and four-course rotations are used involving maize, barley, oats, lucerne, and pasture. This is not so much due to soil groups as to the less rigorous climatic conditions, and to the local tradition of high farming, for the same rotations are used on the chernozemic soils in the Inverell district.

The grey-brown solodic soils are rarely used for wheat growing and the husbandry practices of the few cases encountered were similar to those of the adjacent red-brown earths.

A short fallow is an integral part of continuous wheat growing, and a natural corollary to this is burning the stubble, which is practised by 50 of the 81 farmers as a general rule and by most of the others when wheat follows wheat. This observation is the more striking, since the farmers

TABLE 1

SURVEY OF MANAGEMENT PRACTICES

Soil Group	District	No. of Farmers	Rotation Practised: Wheat Continuously	Rotation Practised: Wheat Continuously with Occasional Lucerne	Rotation Practised: Wheat Continuously with Occasional Year of Oats, Long Fallow, Milo, etc.	Rotation Practised: Alternate Wheat and Oats, or Alternate Wheat and Long Fallow	Stubble Treatment Practised: Grazing, No Burning, Cultivating	Stubble Treatment Practised: Grazing, Burning, Cultivating	Stubble Treatment Practised: Burning Immediately, Cultivating	Type of Cultivation and Average Depth: Disc Plough	Type of Cultivation and Average Depth: Scarifier
Red-brown earths (including red solodic)	Eastern:										
	Tamworth	11	2	1	2	6	6	5	—	11 (4in.)	—
	Manilla	4	1	—	—	3	3	1	—	4 (4in.)	—
	Barraba	2	1	1	—	—	1	1	—	2 (4in.)	—
	Bingara	5	4	1	—	—	5	—	—	5 (4in.)	—
	Total	22	8	3	2	9	15	7	—	22 (4in.)	—
Red-brown earths (including red solodic)	Western:										
	Quirindi	4	3	1	—	1	—	4	—	4 (4½in.)	—
	Gunnedah	6	5	—	1	—	4	2	—	6 (3½in.)	2 (3½in.)
	Narrabri & Boggabri	5	5	—	—	1	—	5	—	5 (3½-4in.)	1 (3½in.)
	Total	15	13	1	3	11	4	11	—	15 (3.8in.)	3 (3½in.)
Total		37	21	4	1	2	19	18	—	37 (3.97in.)	3 (3½in.)
Chernozemic soils	Eastern:										
	Tamworth	8	1	1	2	4	4	3	1	8 (4.3in.)	—
	Bingara	3	3	—	—	—	—	3	—	3 (3.7in.)	—
	Inverell	4*	1	1	—	—	2‡	2	—	4 (3.9in.)	—
	Total	15*	5	2	2	4	6‡	8	1	15 (4in.)	—
Chernozemic soils	Western:										
	Quirindi	4	3	—	1	2	1	2	1	4 (3½in.)	2 (2½in.)
	Gunnedah	9	6	1	2	1	2	7	—	6 (3.2in.)	3 (2¾in.)
	Narrabri & Boggabri	18	12	2	2	3	2	16	—	7 (3½in.)	11 (3.2in.)
	Moree	8	3	3	2	—	—	8	—	5 (3in.)	8 (2.8in.)
	Total	39	24	6	7	6	5	35	1	22 (3.3in.)	24 (2.95in.)
Total		54*	29	8	9	10	11‡	43	2	37 (3.6in.)	24 (2.95in.)
Euchrozems	Inverell	7†	1	1	—	1	2	5	—	7§ (3.1in.)	—
Grey-brown solodic soils	Tamworth	2	1	—	1	1	1	1	—	2 (4in.)	—

* Two farmers have special three-course rotation.
† Three out of seven farmers have special three-course rotation.
‡ Plough-in every third year.
§ One farmer uses a mould board.

contacted represent the ablest and most advanced members of the agricultural community, and the proportion in the community at large must be considerably in excess of this. The value of stubble burning for controlling such weeds as saffron thistle and black oats was advanced by some farmers, but, unlike the southern wheat areas, no mention was made of any virtue of burning as a means of controlling plant disease.

Table 1 shows that, for the red-brown earths as a whole, the stubble is always grazed, and that the practices of stubble burning and stubble ploughing are now almost equally favoured, but the proportion who attempt to plough the stubble is much higher in the east than in the west.

For the chernozemic soils as a whole, in contrast to the red-brown earths as a whole, there is a fourfold predominance of those who burn the stubble before ploughing over those who plough it unburnt, whilst occasional individuals do not even graze before burning and ploughing. Again the east-west differentiation exists, for whilst a slight majority of farmers in eastern districts on chernozemic soil favour burning, in the western districts only about one farmer in eight would attempt to plough unburnt stubble.

These differences in stubble treatment are related to a growing appreciation that for the light soils on sloping country (i.e. particularly the eastern red-brown earths) the practice of burning the stubble is an important factor contributing to soil erosion. At the other extreme, however, (the flat western chernozemic soils) the question of erosion is of little significance, since these soils are virtually immune to sheet- and wind-erosion and the practical difficulties of ploughing-in the stubble often are formidable. The practice of burning the stubble immediately without grazing, is related to cultivation requirements and will be discussed shortly.

For the euchrozems and grey-brown solodic soils, no significant trends can be drawn.

With regard to cultivation practices, the table shows that for the red-brown earths as a whole the disc plough or disc harrow is used almost universally, with only three examples being found of scarifiers alone, all confined to the western districts. By contrast, for the chernozemic soils as a whole, a large minority (40 per cent.) of farmers use the scarifier in preference to the disc plough, and about two-thirds of this minority use the scarifier alone, except where unusual amounts of trash render burning incomplete. The east-west contrast is most marked here, for none of the farmers in the east uses the scarifier in preference to the disc plough on the chernozemic soils, whilst in the western districts a majority prefer the scarifier. This distribution of implement use is closely related to stubble-treatment practice, as the use of the scarifier alone requires previous burning of the stubble.

The average depth of ploughing on the red-brown earths varies from the 4 in. in the eastern districts to 3.8 in. for disc ploughs, and 3.5 in. for scarifiers in the western districts. The corresponding depths for the chernozemic soils in the western districts, 3.3 and 2.9 in. for disc and scarifier respectively may be significantly lower than those on the red-brown earths in the same districts. Even so, the differences still could be an expression of climatic conditions and not soil conditions, for an examination of the field records reveals that, of the 16 farmers visited cultivating both red-brown earth and chernozemic soils on the one property, eight used identical cultivation practices on both groups and eight ploughed shallower on the chernozemic soils. A further interesting correlation is that, in practically every case where scarifiers alone are used, the pH of the surface soil exceeds 7.5. All of these are on the western chernozemic soils.

The whole question of cultivation requirements on the flat chernozemic soils of the drier west is concerned with the effect on moisture relationships of the textural and structural conditions of those soils. The virgin chernozemic soils of the flat plains show a self-mulching clay at the surface developing rapidly into a porous small-cloddy-structured clay, which at about 3 in. changes fairly abruptly into a hard heavy clay of large-cloddy structure and restricted porosity. Except for the large cracks which in the virgin soil extend to the surface, these conditions favour moisture retention in the subsoil, since the continuity of moisture films is broken at 3 in. depth. The purpose of cultivation on such soils is chiefly to conserve moisture by preserving and accentuating these features and by preventing moisture loss through large surface cracks and by weeds. If ploughing is too vigorous and too deep, the larger structural units are disturbed and brought to the surface, cracks are exposed, and no "hard-bottom" at 3 in. is formed; if ploughing is too shallow, weeds are not killed and the continuity of subsurface structure develops too closely to the surface. So the practice has developed upon the flat chernozemic soils of burning the stubble early, in December, and scarifying to 2½-3 in. consistently, after every heavy shower of rain, to renew and preserve immediately the self-mulching structure of the surface, and thus to retain in the subsoil the moisture received from the monsoonal summer showers. Seeding in April at 2½-3 in. ensures that with sufficient rain (60 points) to germinate the seed, the slightly moist hard-bottom at 3 in. can supply sufficient moisture to the young wheat in the early stages. The penetration of the wheat roots down the wide cracks allows the wheat to live, predominantly if necessary, on the subsoil moisture of the previous summer's rains, provided that these were adequate. As evidence of this two farmers reported having grown 5-bag crops of wheat without any winter rains throughout the growing period after germination, using this method of conserving the previous summer's rains in the soil structure. This practice is in contradistinction to that of growing wheat on the current winter rainfall found on the red-brown earths of the southern areas of the State.

Since the larger structural units of the B_1 horizons of the chernozemic soils probably are associated with the higher proportion of sodium on the exchange complex and this in turn engenders higher pH values, a reason is suggested for the use of scarifiers on soils showing a high pH at the surface.

V. The Nutrient Status of the Wheat Soils

The chemical fertility of the soil can be defined as the extent to which it can supply all the nutrients required by the crop in the quantities and at the times required by the plant. In this case, since in no part of the area was there any suggestion that a deficiency of trace nutrients was hindering the growth of wheat, whilst there were definite indications in the field that in certain cases nitrogen deficiency was at least limiting the quantity of protein formed in the grain, attention was concentrated in the first instance on those factors likely to affect the supply of nitrogen to the plant.

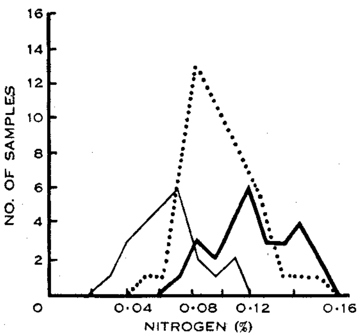

Fig. 1

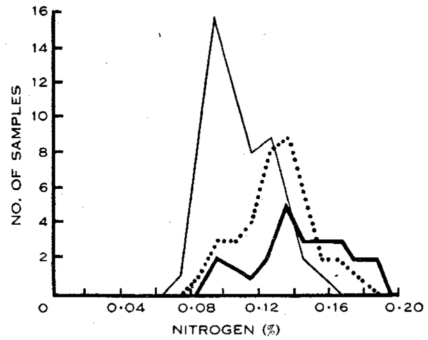

Fig. 2

Fig. 1.—Nitrogen contents of the red-brown earths and red solodic soils.
——— Uncultivated soils.
...... Cultivated soils from eastern districts.
——— Cultivated soils from western districts.

Fig. 2.—Nitrogen content of chernozemic soils.

The nitrogen of the soil is present mainly in the proteins and ligno-proteins of the organic matter, and requires to be broken down by the action of microorganisms to ammonia and nitrate before it can be absorbed by the plant. These transformations are affected by the moisture content, air supply, and temperature, which even in one soil will vary markedly from time to time, and also appear to be affected by such inherent characteristics as base status, level of available phosphorus, etc. which may vary widely from one soil to another. It follows that the total nitrogen content of the soil is only one factor in the rather complex system which determines the availability of soil nitrogen to the plant.

Assuming that most of the plant's supply of nitrogen is obtained as nitrate rather than as ammonia, then the amount of nitrogen available for plant growth at any one time will depend on the balance between the rate at which nitrates are produced from the organic matter and the rate at which they are lost by leaching, absorbed by other microorganisms, or destroyed by denitrification, the latter process being only of importance under anaerobic conditions. These factors may operate differently in different soils, and the operation of any one factor is not necessarily constant under all conditions. Thus, at the lower levels of moisture supply, increases in moisture lead to increases in nitrification, but with further increases in moisture supply nitrification may be reduced by either a lowering of the soil temperature or a diminution of air supply, whilst with still further increases nitrogen may be lost by the leaching away of nitrates, or in cases of flooding by actual denitrification.

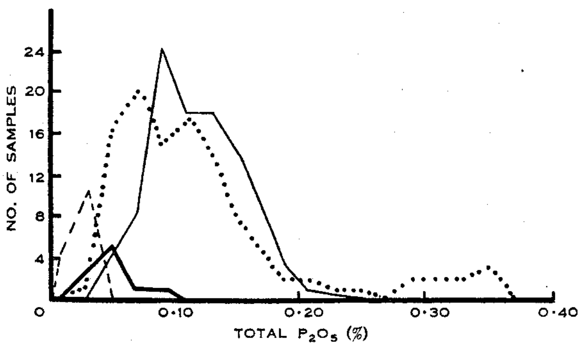

Fig. 3.—Acid-soluble phosphate content of the soils of the north-west wheat belt.

——— Red-brown earths.
. . . . . Chernozemic soils.
- - - - Chernozemic soils (northern).
——— Grey-brown solodic soils.

The interplay of the other factors affecting nitrification has been adequately reviewed in the literature recently, and an exhaustive treatment would not be appropriate here. It is relevant to this work, however, to point out that the base status, pH, and phosphate content have all been shown recently to affect nitrification. It follows, therefore, that even in an area of constant climate, the value to the plant of any given figure for total nitrogen will vary with the changes in another factor (e.g. phosphate), always provided that the variations in supply of the second factor are within the range in which that factor may be limiting. Variations of supply above the level of adequacy would hardly be expected to have an effect.

Nevertheless, in one soil group, where other conditions are constant, and where the total nitrogen content is not believed to be high, there appears to be some justification for using the total nitrogen content as the first approximate measure of nitrogen-supplying powers of the soils of that soil group. The assumption made here is merely that in, say, the chernozemic soils, other things being constant the supply of available nitrogen as nitrate would be proportional to the total quantity of nitrogen present.

In addition to total nitrogen, the figures for organic carbon, total and available phosphates, and pH were determined,* and the results for total nitrogen, acid-soluble phosphate, and pH are given as distribution curves in Figures 1-4, and the results for the different soil groups are given below.

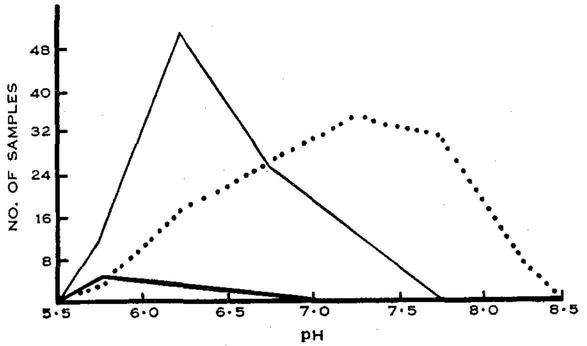

Fig. 4.—pH frequency curves of the soils of the north-west wheat belt.
——— Red-brown earths.
. . . . . Chernozemic soils.
——— Grey-brown solodic soils.

(*a*) *The Grey-brown Solodic Soils*

The surface soils of this group are acidic, although not strongly so, the pH range being from 5.5 to 6.5. They are low in total and available phosphate, and, although the level appears to be adequate for wheat growing in the early stages of cultivation, it is generally too low for the satisfactory establishment of pastures containing legumes, or for good lucerne. The total nitrogen content is very low, being only 0.05 per cent. even in virgin soils, and lower than for any other soils encountered in the region except the solodized solonetz of the Pilliga. Under cultivation this falls rapidly to levels at which it appears to be limiting, i.e. 0.03-0.04 per cent.

(*b*) *The Red-brown Earths and Red Solodic Soils*

These show a wide range of textures and depths. They are not so acidic as the grey-brown solodics, and show a pH range from 5.7 to 7.3.

* The analytical methods used were: nitrogen by Kjeldahl; organic carbon by a modified Walkley-Black; total phosphoric acid by Hall's method (Piper 1944); available phosphoric acid by Truog (Truog 1930); the pH by glass electrode at the sticky point (Doughty 1941).

They differ from the red-brown earths of the southern parts of the State and southern Australia generally in that they are rich in total phosphate, ranging from 0.05 to 0.23 per cent. P_2O_5 with the mode at about 0.10 per cent. The availability of this phosphate is relatively high also, generally running higher than 30 p.p.m. and in some areas going over 100 p.p.m. with isolated parts higher than 1000 p.p.m. Nevertheless, some small areas occur near Tamworth where the level of available phosphate is low enough to allow a response to superphosphate in years of higher rainfall. The content of total nitrogen for the virgin soils is higher in the eastern districts (mode 0.13 per cent.) than in the western areas (mode 0.09 per cent.), whilst for the cultivated soils the modes have dropped to 0.09-0.10 and 0.07 per cent. respectively for the eastern and western districts.

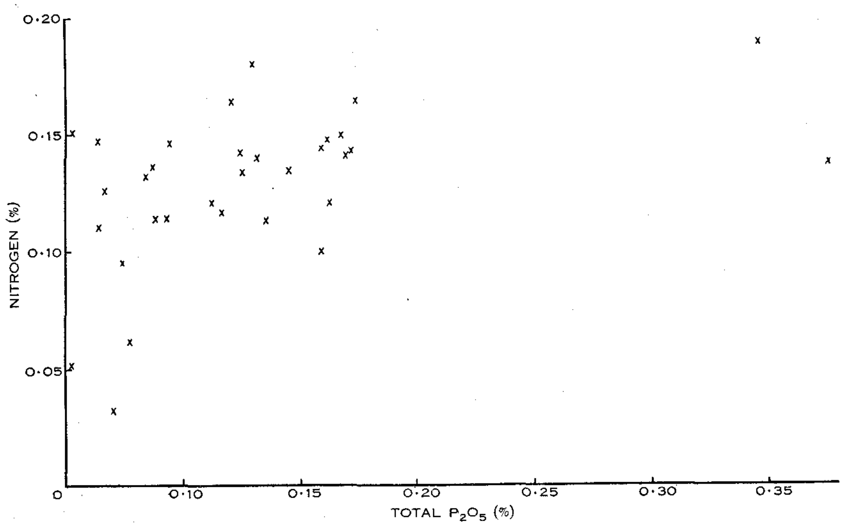

Fig. 5.—Percentage N *v.* total P_2O_5 for virgin soils.

(*c*) *The Chernozemic Soils*

Although generally more alkaline than the soils considered previously, the surface soils do show considerable variation in pH. Those of the eastern districts and the brown chernozemic soils of the gentle slopes of the west show a pH range around 7.0, although extreme values may vary from 5.8 to 7.8. The soils of the treeless plains of the western districts and the northern areas of brigalow-belah woodland show a much higher range, 6.6-8.5, with the mode at about pH 7.5. The total phosphate content of all except the northern areas, although variable, is generally high (0.05-0.15 per cent.) and the available phosphate content is often extremely high, especially for soils on basalt, 400-800 p.p.m. occurring quite commonly, and 1300 p.p.m. in one area. For the soils of the northern wheat districts, both total and available phosphates are much lower, 0.03-0.05 per cent. and 25-55 p.p.m. respectively, and may eventually become limiting for wheat production.

The content of total nitrogen for the virgin soils in all areas is somewhat higher than for the red-brown earths, although not significantly so, ranging from 0.09 to 0.18 per cent., with the mode at about 0.14 per cent., whilst for the cultivated soils the modes have dropped to 0.12 and 0.09 per cent. respectively for the eastern and western districts.

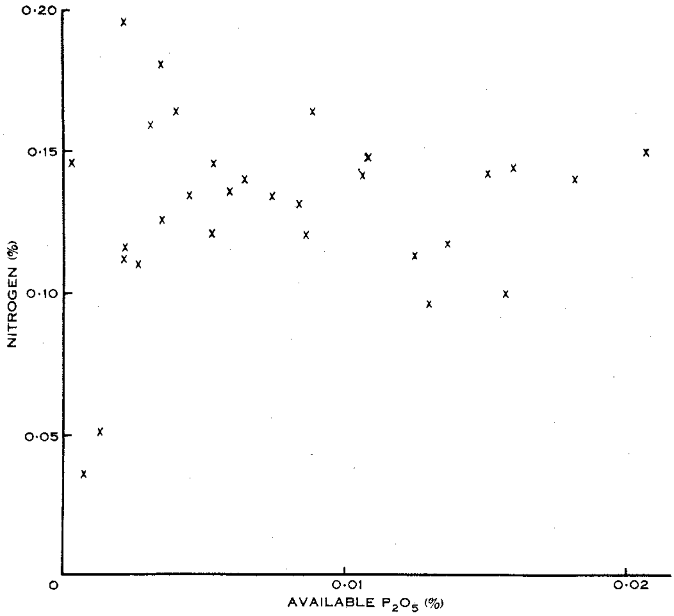

Fig. 6.—Percentage N *v.* available P_2O_5 of virgin soils.

(*d*) *The Euchrozems*

These soils are slightly acid in the surface and the samples collected are fairly evenly distributed between pH 5.7 and 6.9, the mean being pH 6.3. The total phosphate content of these soils is generally high, from 0.09 to 0.27 per cent. P_2O_5, with a mean value of 0.18 per cent., but it does not appear to be as readily available as the phosphates of the chernozemic soils with similar total phosphate contents, for the available phosphate contents range from 16 to 78 p.p.m., with one sample going to 120 p.p.m.

Applications of 1 or 2 cwt/acre of superphosphate have been found beneficial on some of these soils.

The total nitrogen content of these soils is slightly, although not significantly, higher than that of the chernozemic soils, ranging from 0.10 to 0.16 per cent. and showing no evidence of a fall with cultivation.

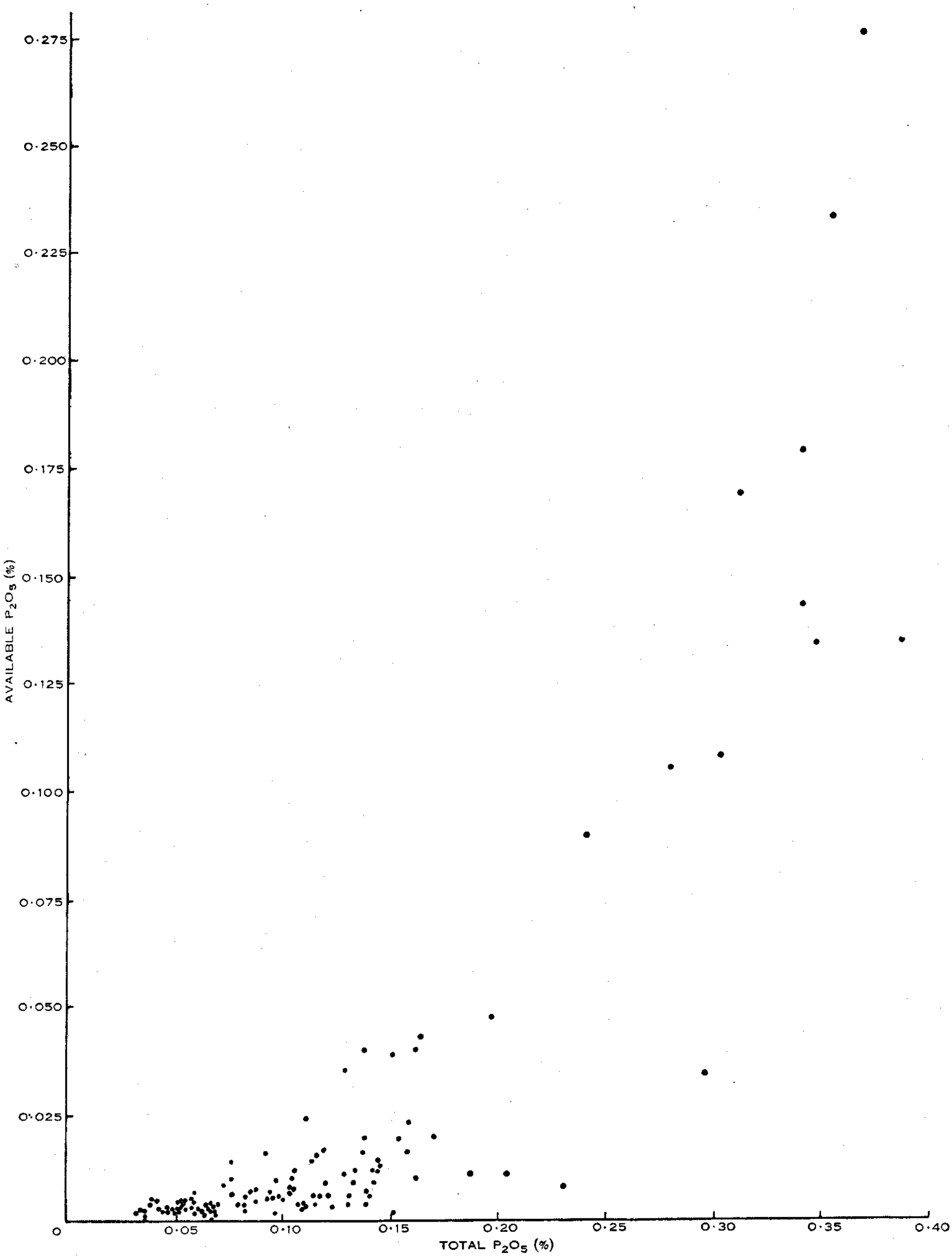

Fig. 7.—Percentage available P_2O_5 *v.* percentage total P_2O_5 for chernozemic soils.

(*e*) *The Sierozems*

These resemble the chernozemic soils in nutrient status. In general they are more alkaline, with a slightly lower content of nitrogen and organic matter. The level of the available phosphate is distinctly lower than in the latter group. Cultivation of these soils has been largely restricted to the pocket of them that extends eastwards between the Pilliga scrub and the Namoi River.

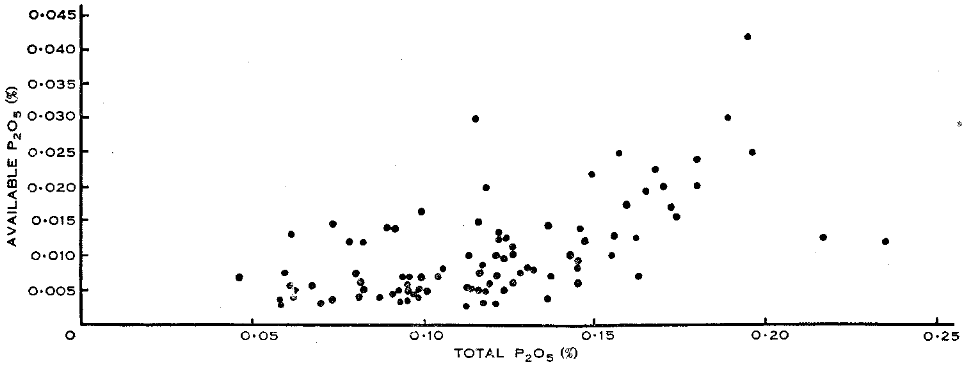

Fig. 8.—Available P_2O_5 *v.* total P_2O_5 for red-brown earths.

The outstanding feature of these analyses is the very high level of total and available phosphate. Nitrogen fixation by leguminous vegetation would hardly be limited by deficiencies of phosphate. This is substantiated by Figures 5 and 6 which show the lack of relationship between nitrogen and phosphate for all uncultivated soils.

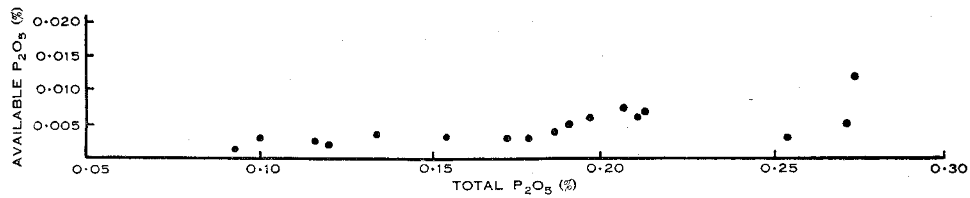

Fig. 9.—Available P_2O_5 *v.* total P_2O_5 for euchrozems.

Contrary to what has been reported generally in the literature, a clear relationship can be seen between the figures of total and available P_2O_5 for both the red-brown earth and the chernozemic soil groups (Figs. 7 and 8). The range encountered is distinctly wider in the chernozemic soils and some very high values for total phosphate are found. Although over the lower ranges (below 0.15 per cent. P_2O_5) the relationship in the two groups is much the same, at the higher levels of total phosphate there is an obvious tendency for the availability of the phosphate to increase until at the highest levels about 10 per cent. of the total acid-soluble P_2O_5 is available by the Truog test.

The euchrozems show a markedly different relationship. The available phosphate figures are distinctly lower than are found in the other two groups at comparable levels of total phosphate (Fig. 9). Comparing them with the more limited group of chernozemic soils from the same area, and expressing the available phosphate as a percentage of the total phosphate, the difference is rather striking, for whereas the mean total phos-

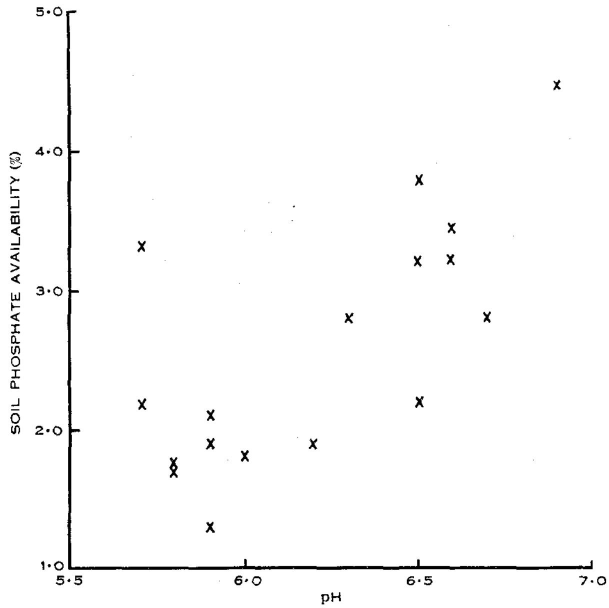

Fig. 10.—Percentage availability of soil phosphate *v.* pH for the euchrozems.

phate figures are 0.189 and 0.115 per cent., the availability of this phosphate is 2.6 and 5.6 per cent. for the euchrozem and chernozemic soils respectively, whilst in the euchrozems, the availability of the phosphate rises with the pH (Fig. 10).

TABLE 2

RELATIONSHIP OF AVAILABILITY OF SOIL PHOSPHORUS TO THE SOIL pH

pH Range	Chernozemic Soils		Red-brown Earths and Red Solodic Soils	
	Number	Mean Availability (%)	Number	Mean Availability (%)
5.5-5.99	3	5.3	11	8.3
6.0-6.49	15	6.7	46	8.3
6.5-6.99	23	6.4	25	8.6
7.0-7.49	31	9.5	12	10.3
7.5-7.99	29	9.4	1	14.9
8.0-	4	10.1	—	—

Both the chernozemic soils and the red-brown earths show a tendency for the availability of the phosphate to rise with pH, but considerable variation is found at each pH range (Table 2).

VI. The Effect of Wheat Growing on the Topsoil

From an examination of the analytical results it is clear that the main effect of cultivation has been to lower the figure for nitrogen and organic carbon, with but little effect on the figure for phosphate and pH.

The effect on the nitrogen content of the topsoil is shown in the frequency distributions for the two major soil groups (Figs. 1 and 2), whilst the change in the nitrogen level with the number of wheat crops grown can be seen from Table 3 which includes all the soils that have grown wheat, irrespective of the husbandry practices.

Table 3

THE EFFECT OF WHEAT CULTIVATION ON THE NITROGEN CONTENT OF THE TOPSOIL, FOR ALL SOILS SAMPLED

Cropping History	Red-brown Earths and Red Solodic Soils				Chernozemic Soils			
	Eastern Area		Western Area		Eastern Area		Western Area	
	No.	N (%)	No.	N (%)	No.	N (%)	No.	N (%)
Never cultivated	17	0.129	7	0.096	11	0.147	12	0.148
Wheat crops: 9 or less	13	0.114	8	0.085	9	0.135	28	0.118
Wheat crops: 10-19	11	0.096	6	0.063	8	0.128	30	0.111
Wheat crops: 20-29	13	0.090	6	0.064	8	0.126	5	0.098
Wheat crops: 30 or more	10	0.094	7	0.067	6	0.119	8	0.097
Mean for all soils that have grown 10 or more wheat crops	34	0.093	19	0.065	22	0.125	41	0.107
Mean for all soils that have grown 10 or more wheat crops as % of the N content of uncultivated soil	72.1		67.5		84.2		74.2	
Cropping intensity for all soils that have grown 10 or more wheat crops, expressed as % of the max. possible	76.1		76.6		65.6		78.0	

If the nitrogen content of the soils which have never been cultivated can be taken as a measure of that present originally in all soils, it can be seen that both groups show a loss which varies from 16 per cent. in the chernozemic soils of the eastern parts, to 32 per cent. in the red-brown earths of the western areas. That the nitrogen level of the western red-brown earths is distinctly lower than that of their eastern counterparts is perhaps partly due to the lower rainfall, and partly to the parent material, for they are derived largely from Jurassic sandstone and are quite light in texture, whilst those of the eastern parts are derived mainly from shales, slates, schists, mudstones, and conglomerates, and are distinctly heavier. The losses from the red-brown earths of both areas are of the same magnitude. In the field these soils show obvious signs of erosion. Those of the east seem now to develop a compacted surface very quickly, and appear on superficial examination to be eroding more seriously than those of the west.

Although the ranges of soil nitrogen largely overlap, the mean nitrogen content of the never cultivated chernozemic soils is distinctly higher than that of the red-brown earths; although the decline in the chernozemic soils of the west may be of the same order as in the red-brown earths, the initial decline is slower. This may be due to the higher nitrogen content of the deeper layers of the chernozemic soils, aided by the slow inversion of the soil in the gilgai process (Hallsworth, Robertson, and Gibbons 1954), or it may be due to the more ready growth of medics on these more calcareous soils, and the resultant gain in nitrogen in those years when no wheat is grown (Purchase, Vincent, and Ward 1949).

TABLE 4

RELATIONSHIPS BETWEEN RAINFALL AND CARBON : NITROGEN RATIO FOR THE RED-BROWN EARTHS AND RED SOLODIC SOILS

Mean annual rainfall (in.)	20	21	22	23	24		25	26	27	29	32	Mean All Soils
No. of samples	10	14	4	7	2	4	19	16	10	3	4	
Mean C/N ratio–												
Western	17.2	17.6	—	—	15.5	—	—	—	—	—	—	17.3
Eastern	—	—	15.6	15.9	—	13.9	14.3	13.9	14.8	15.1	13.4	14.6

The decline in the nitrogen content of the eastern chernozemic soils is much less than in either the western chernozemics or the red-brown earths. This is most probably due to the fact that wheat has been grown much less frequently on these soils, and that lucerne or natural pasture has occupied the soil for a larger proportion of the time since cultivation began.

In general the figures for organic carbon follow those for nitrogen, with certain outstanding differences, and it does not appear that cultivation and wheat growing have had any consistent effect on the carbon: nitrogen ratio. In the red-brown earths, however, there is a distinct difference between the mean figures for the eastern and western areas. This appears to be a function of parent material again, rather than of rainfall, for although the ratio declines as the rainfall increases from 20 to 25 in. no response is shown with further increases (Table 4). Individual values range from 21.6 in an uncultivated soil in the west to 11.9 for a cultivated soil in the east.

The chernozemic soils are much more uniform. The extremes range from 17.9 in a cultivated soil to 10.5 in an uncultivated soil, both in the Gunnedah district. In contrast to the red-brown earths, the carbon: nitrogen ratio shows a slight but non-significant increase from the uncultivated to the cultivated soils, and shows a distinct tendency to increase at higher rainfalls (Table 5).

TABLE 5

THE CARBON : NITROGEN RATIO OF THE CHERNOZEMIC SOILS

District	All Soils		Uncultivated Soils		Mean Annual Rainfall (in.)
	No.	C/N ratio	No.	C/N ratio	
Western					
Gunnedah district	38	13.2	8	13.9	21.9
Narrabri district	22	14.8			22.4
Northern district	18	14.9	2	14.7	22.9
Eastern					
Tamworth-Nundle district	25	14.9	8	14.4	24.7
Inverell-Bingara district	11	15.2	3	15.1	26.7
Mean		14.5		14.0	

VII. The Effect of Cultivation Practices

The effect of the different cultivation practices cannot be so clearly demonstrated as would be desired, or indeed as might have been anticipated from Table 1. This arises from the fact that Table 1 has been based on the cultivation practices being followed at the time of the survey in 1948-49, and in many cases on the older soils, the practices have been changed recently from what had originally been used. On some of the red-brown earths, for example, wheat was first grown in alternate years with a bare fallow in between. This changed around 1913-14 to wheat every year, burning the stubble and using a short bare fallow. In the last 10 years this has commonly changed again to wheat alternating with a grazed fallow, or with grazing oats.

In classifying the analytical results it has been necessary subsequently to group them according to the practices of the last 10 years. At the same time it became obvious that no soil had actually carried wheat every year for more than a few years. Either by accident or design most wheat paddocks have been out of cultivation for a longer or shorter period. Drought years, economic exigencies, or the whim of the farmer may have resulted in an odd year under long fallow or natural pasture even in those instances where the deliberate aim was to secure a wheat crop year after year. As a result it was not possible to make a valid separation of the results for those paddocks falling under rotation (3) above, and most of the figures are included with those of rotations (1) and (4). At the same time the intensity of cultivation has been measured as the frequency with which wheat has been grown, expressed as a percentage of the maximum possible since the land was first cultivated. Thus a paddock that had been first ploughed 10 years before and had carried 10 wheat crops, would have a frequency of 100 per cent.

The results for those paddocks that were first cultivated 10 years or more ago are given in Table 6.

Two features are outstanding. The first shows that in the north-west lucerne is an effective means of raising or restoring the nitrogen level of the soil. This is in accordance with expectations, and with the claims of several farmers. The mean difference shown is not very great because any paddock that had grown lucerne in the last 10 years was included, even though seven or eight wheat crops had been taken since the lucerne was ploughed in. The effect in individual cases, where lucerne had been occupying the ground for 4 or 5 years at the time of sampling, was very striking and in several cases the nitrogen level under well-established lucerne exceeded that in adjacent soils that had never been cultivated.

The second is that the nitrogen level of paddocks under continuous wheat are not significantly different in nitrogen content from those where wheat is grown alternately with either a long fallow or grazing oats, except for the western red-brown earths. This lack of difference might have been attributed to the fact that many of the samples included had been under wheat continuously until very recently, but it can be seen that the average frequency of wheat cropping is much less for those soils on the wheat/grazing oats or wheat/long fallow rotations. These rotations have been advocated in the north-west as a means of maintaining or restoring soil fertility, particularly on the red-brown earths, but the figures obtained here lend no support to this contention.

Two isolated cases are worthy of further mention.

One property was encountered, near Boggabri, where wheat was grown in alternate years with a clean, frequently cultivated fallow in between. The nitrogen level was almost the lowest found amongst the western chernozemic soils, in spite of the fact that the cropping frequency was much lower than average, and the topographic situation precluded any possibility of water erosion. The soil was one of the most alkaline encountered, and, in spite of the relatively low nitrogen level, was still growing premium wheat. It is tempting to link this with the possibility of nitrate accumulation during the long clean fallow, but further work is obviously necessary.

On one property at Carrol, what appears to be a unique attempt has been made for more than 25 years to plough in the stubble, whilst growing wheat every year, avoiding burning except in years of excessively bulky vegetative growth. The difference in the average nitrogen figures for these soils is quite striking, and the average is higher than for any other

TABLE 6

RELATIONSHIP BETWEEN CULTIVATION PRACTICES AND SOIL NITROGEN

Cultivation Practice	Eastern Districts				Western Districts			
	No. of Paddocks	Nitrogen Content		Frequency of Wheat (%)	No. of Paddocks	Nitrogen Content		Frequency of Wheat (%)
		per 100 g Soil	as % of Uncultivated			per 100 g Soil	as % of Uncultivated	
Red-brown earths and red solodic soils								
Uncultivated	17	0.129	100	—	5	0.092	100	—
Continuous wheat	16	0.094	72.9	83.9	13	0.064	69.7	80.2
Alternate wheat/grazing oats or wheat/long fallow	13	0.094	72.9	66.9	3	0.074	80.4	55.6
Continuous wheat with occasional lucerne	10	0.110	85.2	58.7	4	0.075	83.2	67.0
Chernozemic soils								
Uncultivated	10	0.145	100	—	10	0.150	100	—
Continuous wheat	10	0.113	78.2	79.7	31	0.109	72.7	84.4
Alternate wheat/grazing oats or wheat/long fallow	11	0.120	83.0	56.4	8	0.102	68.2	55.2
Continuous wheat with occasional lucerne	5	0.129	88.8	53.4	9	0.118	78.7	61.0
Wheat/clean fallow	—	—	—	—	4	0.087	58.1	43.2
Stubble mulch	—	—	—	—	4	0.141	93.8	78.1

cultivation practice, in spite of the fact that wheat has been grown in nearly 8 years in 10, including those years missed because of drought. The soils are chernozemic, alkaline, and high in phosphate, and, as might be expected from the figures, they still grow premium wheat. Although clearly it would be unwise to generalize from one property, the fact that after 20 years of cultivation, these paddocks show a nitrogen content of 0.14 per cent., approaching the order of virgin soil of the same type, warrants further inquiry into the practice particularly when comparison is made with the nitrogen content of 0.11 per cent. which is the mean for all western chernozemic soils that have carried between 10 and 20 wheat crops.

At present a considerable volume of opinion would be against an extension of the practice, on the grounds that the soil would be left too open, or that the incorporation of this large quantity of material, mainly carbohydrate in nature, would lead to a great proliferation of the soil microflora and consequently reduce the nitrate nitrogen available for the subsequent wheat crop. The very low levels of total nitrogen observed in some of the western red-brown earths suggests that, if as much straw were ploughed in as is being incorporated at Carrol, a serious nitrogen deficiency would be induced. It seems likely that a certain minimum level of nitrogen and possibly of phosphate would be necessary for the practice to have the success it appears to have in this case.

VIII. The Effect of the Soil on the Wheat Crop

At the time of sampling, an estimate was obtained from the farmer of the average yield of each paddock sampled. Although it was obvious in some cases that the figure was over optimistic, and failed to allow for crop failures, where it was possible to check the estimate with actual yield figures it was found that in general the discrepancy was not large enough to invalidate the figures obtained. The yield figures obtained are shown in relation to the nitrogen status in Table 7.

From these results it appears that whilst the average yield of wheat of the chernozemic soils is distinctly higher than that of the red-brown earths, the yield obtained on either soil does not show any differences between the eastern and western areas. Thus for the chernozemic soils, a content of 0.09-0.10 per cent. of soil nitrogen is sufficient for a 10-bag crop, and further increases in soil nitrogen are not accompanied by corresponding increases in yield of grain. In the red-brown earths, however, not only is the yield obtained lower at comparable nitrogen levels, but several soils have been sampled from the western areas where nitrogen appears to be the limiting factor, for the average crop appears to be closely related to the total nitrogen content. The difference between the two groups is probably related to the difference in distribution of the soil organic matter, since the total soil nitrogen is largely concentrated in the topsoil of the red-brown earths, but is distributed through greater depths of the chernozemic soils. A change in the nitrogen level of the top 6 in., which was all that was studied in this investigation, consequently means a much greater proportionate change in the red-brown earths than it would in the chernozemic soils. It is interesting to note that in the few examples collected from the grey-brown solodic and the solodized solonetz soils, in both of which the organic matter profile resembles that of the red-brown earths, cases were also encountered where the figures suggest that nitrogen was limiting, although the absolute level was different. Thus at Kootingal the yields for three wheat paddocks were 12 bags, 10 bags, and 8 bags, on soils containing respectively 0.415, 0.388, and 0.280 per cent. nitrogen.

TABLE 7

RELATIONSHIP OF SOIL NITROGEN TO AVERAGE YIELD IN BAGS PER ACRE

Nitrogen Content (%)	Western Chernozemic		Eastern Chernozemic		Western Red-brown Earths		Eastern Red-brown Earths	
	No. of Samples	Av. Crop	No. of Samples	Av. Crop	No. of Samples	Av. Crop	No. of Samples	Av. Crop
0.03-0.04	—	—	—	—	—	—	1	5
0.04-0.05	—	—	—	—	—	—	1	6
0.05-0.06	—	—	—	—	—	—	3	7.3
0.06-0.07	—	—	—	—	—	—	3	8.5
0.07-0.08	—	—	—	—	4	7.25	1	8.5
0.08-0.09	4	10.0	1	13	10	7.90	1	8.5
0.09-0.10	11	10.1	3	12	6	7.67	1	9.0
0.10-0.11	11	10.3	3	11.3	6	7.0	1	9.5*
0.11-0.12	4	10.6	2	9.5	4	7.75	—	—
0.12-0.13	6	10.5	2	11.0	—	—	—	—
0.13-0.14	—	—	4	9.3	—	—	—	—
0.14-0.15	—	—	1	9.0	—	—	—	—
0.15-0.16	—	—	2	9.5	—	—	—	—
0.16-0.17	—	—	1	10.0	—	—	—	—
Total no. of samples and average yield	36	10.26	19	10.48	30	7.5	12	7.82

* Where the farmer's estimate was, say, 9-10 bags, it has been recorded as 9.5 etc.

When the yield falls appreciably, the farmer considers the land "wheat-sick" and the paddock is usually left fallow for several seasons, or sown to lucerne, except on those smaller farms where economic pressure forces the farmer to continue to grow wheat. The number of cases encountered in which soil nitrogen appears as a factor limiting yield is consequently rather surprising. It is notable that they are concentrated mainly in the western red-brown earths, where the total nitrogen level is low, and the carbon: nitrogen ratio high, which would be expected to limit the availability of the nitrate produced from the soil organic matter.

Part of the difference between the red-brown earths and chernozemic soils and the differences within these groups are probably attributable to differences in the nitrate balance of the soil, which will be determined by the rate of production of nitrate from the soil organic matter and its rate of removal by leaching. Higher rainfall on the more porous red-brown earths would lead to increased losses by leaching more readily than on the less permeable chernozemic soils. At the same time, the generally higher base status of the chernozemic soils might be expected to promote nitrification, and these factors as well as the deeper penetration of the organic matter in the chernozemic soils must be remembered in considering the variations in yield and quality of the wheat grown on them.

The relationship between soil and wheat quality is more difficult to assess other than in a purely subjective manner. The picture in all the wheat producing soils is much the same. Following clearing, the first crop of wheat gives a high yield but the crop tends to lodge in a normal season. In consequence oats for grazing is frequently grown on new country "to take the fire out of the soil". The following crop is frequently Pusa, which is a high quality wheat yielding a premium when grown on fertile soil. After 2-4 years, depending on soil type, Pusa shows "mottling" of the grain and is replaced by other varieties which may command a premium for a number of years. Subsequently other varieties are grown which give a higher yield, but do not command a premium. These changes accord with the trends shown to occur in the nitrogen content of the soil under cultivation. In general it seems that premium samples of wheat are now rarely obtained on the red-brown earths of eastern parts, and but little more frequently in the western parts. On most of the chernozemic soils, however, premium samples are grown in suitable seasons, although most of the farmers do not expect to grow them on their old wheat land. Land that has grown a lucerne crop for a few years commonly gives premium samples the first year or so after bringing back to wheat, even though the nitrogen level may not be as high as that on old wheat paddocks in the vicinity. The newly added nitrogen from the lucerne appears to be more readily available than that which has persisted for a longer period in the organic matter of the soil. Further work on this problem is obviously necessary.

IX. Discussion

The factors affecting the level and availability of nitrogen in soil have been recently reviewed by Ensminger and Pearson (1950), who have pointed out that a decline in the organic matter and nitrogen content following the cultivation of virgin soils has been almost universal.

For Australia, discussions of the general trends of soil fertility have been published by Forster (1950), Teakle (1951), and Sims (1953), whilst the effects of cereal cultivation in Victoria have been considered by Penman (1951).

The results obtained in the investigation show a general decline in nitrogen content with cultivation. They agree with Penman's results in that the fallow/wheat rotation shows a lower nitrogen content than continuous wheat, but, whilst at Longerenong the introduction of a season of pasture almost halved the losses, the introduction of a season of grazing oats or grazed fallow in north-western New South Wales was literally without effect on the losses recorded.

In accordance with the findings of Purchase, Vincent, and Ward (1949) that under the cultivation practices adopted in the north-west the natural regeneration of medics in volunteer pastures is very slow, the results obtained show that the nitrogen yield by this means is quite insignificant.

Sowing down to a legume, in this case lucerne, rather than relying on volunteer vegetation, appears to be as valuable in the north-west as the use of subterranean clover has been in Victoria (Bath 1951), and a rotation of lucerne for several years followed by continuous wheat for several years seems likely to maintain or even enhance the level of soil nitrogen.

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XI. References

Bath, J. G. (191).—Brit. Commonw. Sci. Offic. Conf., Spec. Conf. Agric., Aust. 1949, Proc., p. 448. (H.M.S.O.: London.)

Doughty, J. L. (1941).—*Sci. Agric.* 22: 135.

Ensminger, L. E., and Pearson, R. W. (1950).—"Advances in Agronomy." Vol. 2. (Academic Press: New York.)

Forster, H. C. (1950).—*J. Aust. Inst. Agric. Sci.* 16: 44.

Gibbons, F. R., and Hallsworth, E. G. (1951).—The Soils of the Namoi Region. "The Namoi Region — Survey of Resources." (Govt. Printer: Sydney.)

Hallsworth, E. G., Colwell, J. D., and Gibbons, F. R. (1953).—*Aust. J. Agric. Res.* 4: 305.

Hallsworth, E. G., Costin, A. B., and Gibbons, F. R. (1953).—*J. Soil Sci.* 4: 241.

Hallsworth, E. G., Robertson, G. K., and Gibbons, F. R. (1954).—*J. Soil Sci.* 5 (in press).

Penman, F. (1951).—Brit. Commonw. Sci. Offic. Conf., Spec. Conf. Agric., Aust. 1949, Proc., p. 457. (H.M.S.O.: London.)

PIPER, C. S. (1944).—"Soil and Plant Analysis." (Hassell Press: Adelaide.)
PURCHASE, H. V., VINCENT, J. M., and WARD, L. (1949).—*J. Aust. Inst. Agric. Sci.* **15**: 112.
SIMS, H. J. (1953).—*J. Aust. Inst. Agric. Sci.* **19**: 89.
TEAKLE, L. J. H. (1951).—*Agric. Gaz. N.S.W.* **62**: 397.
TRUOG, E. (1930).—*J. Amer. Soc. Agron.* **22**: 874.