FERTILITY STUDIES ON THREE RED EARTH SOILS OF THE DALY BASIN, NORTHERN TERRITORY

by
K. J. Day
Department of the Northern Territory
Animal Industry and Agriculture Branch

TECHNICAL BULLETIN NO.

FERTILITY STUDIES ON THREE RED EARTH SOILS OF
THE DALY BASIN, NORTHERN TERRITORY

by

K.J. Day
FERTILITY STUDIES ON THREE RED EARTH SOILS OF THE DALLY BASIN, NORTHERN TERRITORY

by

K.J. Day

Land Conservation Section, Animal Industry and Agriculture Branch, Department of the Northern Territory, DARWIN, N.T.
FOREWORD

This study forms part of the National Soil Fertility Project initiated by C.S.I.R.O. Division of Soils in 1967. Hallsworth (1969) stated that the aim of this project was to determine which, of all the soil factors recognized in a soil profile, are those most closely related to plant production. If such soil factors can be determined precisely, it is then possible to enquire as to the extent by which they can or should be altered to make the best use of our soil resources within various climatic constraints.

Large areas of deep sandy and loamy red earths occur commonly in the Daly Basin (Figure 1). Land use on red earth soils in this region has primarily been grazing by beef cattle on mainly native pastures, with small areas of sown Townsville Stylo (Stylosanthes humilis) pastures and cash crops. It is thought that these soils have the greatest potential for dryland grain sorghum production and pasture improvement, however their development is held back by problems of chemical fertility, soil stability and physical limitations. In view of such existing problems, representative soils of three widely occurring red earth families Tindall, Blain and Emu were studied under the auspices of the National Soil Fertility Project. Grain sorghum (Sorghum bicolor Dekalb E57) was used as the test plant.

To clarify the results of this study three papers have been compiled separately under the following titles:

1. Morphological, physical and chemical characteristics;

2. Leaching of nitrate under grain sorghum in a tropical monsoonal climate;
3. Grain sorghum fertilizer requirements under dryland conditions.

It is the purpose of these papers to demonstrate the importance of certain critical soil physical and chemical characteristics which influence soil water and nutrient availability. The recognition of such interactions is essential in the management of crops such as grain sorghum in the tropical monsoon climate.
1. Morphological, physical and chemical characteristics

K.J. Day
SUMMARY

Resource surveys in the Daly Basin of the Northern Territory have shown that a number of separate soil families may be distinguished within the red earth Great Soil Group. This study involves soils of three widely occurring red earth families, Tindall, Blain and Emu.

Parent material differences are thought to be responsible for quite different physical characteristics between the three soils. The loamy Tindall and Emu soils have gradational texture profiles in contrast to the Blain which is characterized by a very sandy surface horizon overlying a loamy subsoil. Infiltration rates for initially dry soils were found to be $11.8 \times 10^{-3}$ cm per sec for the Blain in comparison to $5 \times 10^{-3}$ per sec for the Tindall and Emu soils. After 20 minutes flooding, infiltration rates were greatly reduced to relatively constant values of $3.3 \times 10^{-3}$ per sec for the Blain, $0.5 \times 10^{-3}$ per sec for the Tindall and $0.25 \times 10^{-3}$ per sec for the Emu soil. Moisture retention characteristics are quite different between surface depths of the three soils, however this difference is reduced with depth. The Emu soil retained 13.52 cm of water between $-1/3$ and $-15$ bar to a depth of one metre, the Tindall 7.67 cm per m and the Blain 5.56 cm per m.

All three soils are low in base exchange capacity, phosphorus and organic carbon and nitrogen, particularly the Blain soil.
Areas of loamy red earths

Areas of sandy red earths

Areas of mixed loamy red earths and other soils.

Figure 1. Map showing the general distribution of red earths in the Daly Basin and location of field trial sites.
INTRODUCTION

Information on the physical and chemical characteristics of certain red earths is available as a result of soil analyses conducted in association with the broad scale land system survey by Stewart (1956). Further soil analyses were published by Aldrick (1972) following detailed land unit surveys. More specific field studies on soil physical and chemical properties of agronomic importance have been confined to areas of red earths located on or in close proximity to the C.S.I.R.O. Reseach Station, Katherine (Slatyer, 1954, 1955; Arndt, 1961; Arndt and Phillips, 1961; Arndt, Phillips and Norman, 1963; Arndt and McIntyre, 1963; Norman, 1966).

Stewart (1956) described several soils, then classified as lateritic red earths, among them the loamy Tippera and the sandy Cockatoo soil families. Van de Graaff (1965) retained both family names as described and proposed a new soil family Blain for previously undescribed gradational soils with sandy upper horizons and loamy subsoils.

Following more detailed resource survey work the classification was revised by Aldrick (1972) using the system proposed by Stace et al. (1968). Blain family soils now fall into the sandy red earth sub-group, which includes chiefly gradational soil profiles and one series of texture contrast profiles. The original Tippera family which contained a wide group of soils has been subdivided into three families of the loamy red earth sub-group, Tindall, Tippera and Emu. Nomenclature in this study is based on this recent work.
This paper describes the morphological, physical and chemical characteristics of representative soils of the Tindall, Blain and Emu soil families, and attempts to highlight important differences which are likely to limit soil water and nutrient supply under a cropping regime. Subsequent papers in this series describe the practical consequences of these differences on the growth of grain sorghum crops in a tropical monsoonal climate.

ENVIRONMENT

Soil genesis

The loamy red earth soils, Tindall and Emu, are thought to be derived from shale and siltstone sediments respectively, interbedded with more resistant limestone (Aldrick, 1972). Bands of structured material appear to be the products of weathering of these sediments in Tindall subsoils, while layers of partly weathered siltstone are usually encountered at a depth of less than one metre in the Emu. The origin of sandy red earths of the Blain family is not as clear. These soils appear to be residual following deep weathering of arenaceous sediments of colluvial/alluvial origin (Mabbutt, 1965; Wright, 1965), however, evidence indicates that weathering of siliceous limestone of Middle Cambrian age may be responsible for their development in other areas.

Climate

Slatyer (1960) described the characteristics of the climate of the Katherine area, and more recently Fitzpatrick (1965) summarized the climate of the Daly Basin. Mean annual rainfall ranges from 704 mm at Willeroo Station in the south to 1,298 mm
at Daly River in the north. Seasonal rainfall distribution varies little throughout the area which experiences a short summer rainfall season from October to April. Annual rainfall variability was found to increase from 17.3 per cent for Daly River to 27.5 per cent for Willeroo Station over an identical 27 year period. Rain usually falls in groups of several consecutive wet days. Each wet period may be interspersed with periods of dry weather up to two weeks or more in length.

**Vegetation**

The native vegetation occurring on all three red earths has been described by Robinson (1972). Tindall soils usually have an almost monospecific uniform stand of *Eucalyptus oligantha* associated with perennial grasses (*Sehima nervosum* and *Themeda australis*). This plant community is low woodland.

The open forest plant community on Blain soils is dominated by *E. tetrodonta* with some *E. miniata*, subordinate ironwood (*Ethyrophleum chlorostachys*) and *E. foelscheana*. Annual sorghum (*Sorghum stipoides*) is the dominant associated grass.

A woodland community develops on Emu soils, dominated by *E. tectifica* and *E. foelscheana* with perennial grasses (*Sehima nervosum* and *Themeda australis*). In drainage floors, Emu soils usually have an open forest dominated by *E. miniata*, associated with perennial grasses including *Coelorachis rotthoelloides* and *Heteropogon triticeus*.

**METHODS**

The Tindall site was located on the Department of the Northern Territory Experimental Farm, Katherine and Blain and
Emu sites on Tipperaty Station (Figure 1). The land at each site was under native grass fallow with no previous fertilizer history.

All sampling was conducted from 1 m soil pits during September of each year, towards the end of the annual dry season. Terms used in describing soil morphology were as defined by the U.S.D.A. Soil Survey Manual (1951) and Northcote (1971). Munsell soil colours were determined in the moist condition.

Surface transect sampling had shown each site to be chemically quite uniform. Prior to any cultivation, four undisturbed soil cores were taken to a depth of one metre from each site for chemical analysis, and for certain of the physical analyses. Clay minerals were determined by X-ray diffraction and particle size distribution by the plummet balance method described by Hutton (1955) for normal soils. Infiltration rates were measured in the field using the concentric ring technique similar to that of Bertrand (1965). After allowing 48 hours free drainage following consistent rainfall, "field capacity" was measured by gravimetric soil moisture sampling. Slight compaction occurred at depth in the soil cores removed for bulk density determinations, however, results compare favourably with those found for similar soils in the area (R.J.K. Myers, personal communication).

Moisture tension determinations were conducted on disturbed soil material, sieved to less than 2 mm. Duplicate samples were taken from a bulked sample for each of the nine tension intervals determined. Sample rings 1 cm high and 5 cm in diameter were used on both pressure and suction plates.
Initially samples were wet up by a flooding technique and more recently under a tension of 5 cm water. Procedures used for moisture tension determinations followed those of Loveday (1974).

Total soluble salts, chloride and pH were determined by the triple-electrode method of McLeod, Stace, Tucker and Bakker (1974) on 1:2.5 soil-water suspension, shaken for 16 hours. Organic carbon was determined by autoanalyser following digestion by a modification of the Walkley - Black technique. The automated distillation technique of Keay and Menage (1969), following a modified Kjeldahl digestion was used to determine organic nitrogen. Total P, K and S were measured by X-ray fluorescence. Bicarbonate soluble phosphorus and potassium were extracted in 1:100 soil - 0.5M NaHCO₃ (pH 8.5) suspension shaken for one hour. Phosphorus was then determined by an automated colorimetric technique, and potassium by atomic absorption. Bicarbonate soluble sulphur was extracted using a 1:4 soil - 0.5M NaHCO₃ (pH 8.5) suspension shaken for 90 minutes, then determined by the automated distillation technique of Keay, Menage and Dean (1972). Exchangeable cations were measured following leaching with IN ammonium chloride (pH 7.0).

RESULTS

Soil morphology

A summary of the morphological properties of the three soils is presented in Table 1. The A₁ horizon of the Blain soil is deep and extremely sandy, with a consistency rating of loose or soft in the dry state. In contrast the Tindall and Emu soils have much finer textures in the A₁ horizon, hence they have a compacted surface appearance with hard to very hard consistency ratings in the dry state.
<table>
<thead>
<tr>
<th>Attribute</th>
<th>Tindall</th>
<th>Blain**</th>
<th>Emu***</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A₁</strong> HORIZON</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thickness</td>
<td>15-25 cm</td>
<td>30-40 cm</td>
<td>15-20 cm</td>
</tr>
<tr>
<td>Texture</td>
<td>Clay loam with sand</td>
<td>sand to loamy sand</td>
<td>loam to clay with sand</td>
</tr>
<tr>
<td>Colour</td>
<td>2.5YR3/4</td>
<td>5YR3/3-2.5YR3/4</td>
<td>5YR3/3</td>
</tr>
<tr>
<td>Gravel occurrence</td>
<td>Less than 2%</td>
<td>Absent</td>
<td>Absent</td>
</tr>
<tr>
<td><strong>A₂</strong> HORIZON</td>
<td>Absent</td>
<td>Absent</td>
<td>Absent</td>
</tr>
<tr>
<td><strong>B</strong> HORIZON</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Texture</td>
<td>Light-medium to medium clay</td>
<td>light medium clay to medium clay</td>
<td>clay loam to light clay</td>
</tr>
<tr>
<td>Colour</td>
<td>2.5YR3/6 - 10R3/6</td>
<td>10R3/4 - 10R3/6</td>
<td>10R3/4 - 10R3/6</td>
</tr>
<tr>
<td>Structure</td>
<td>Weak blocky</td>
<td>Massive</td>
<td>Massive</td>
</tr>
<tr>
<td>Fabric</td>
<td>Smooth ped</td>
<td>Earthy</td>
<td>Earthy</td>
</tr>
<tr>
<td>Gravel occurrence</td>
<td>2 to 10% ironstone nodules &lt;5 mm in diameter</td>
<td>Absent</td>
<td>Less than 2% ironstone and manganese nodules &lt;5 mm in diameter</td>
</tr>
</tbody>
</table>

* Tindall 14°24'S 13°07'E
** Blain 13°48'S 13°10'E
*** Emu 13°35'S 13°05'E
The Blain soil has a duplex texture profile and is massive throughout whereas the B horizon of the Tindall exhibits weak blocky structure, with some smooth ped fabric. The Emu soil is massive throughout with a distinctly lighter textured B horizon that the other two soils.

**Physical characteristics**

Particle size distributions (Table 2) substantiate the various textures referred to in the morphology section. The predominance of fine sand and silt sized particles is a distinctive feature of the Emu soil.

Kaolinite is the dominant clay mineral for the Tindall soil and to an even greater extent for the Blain. For the Emu soil, illite is the dominant clay mineral throughout the profile, with a trace of vermiculite in the subsoil. Expanding or swelling clay minerals are absent from all three red earths (Table 2).

The moisture contents expressed in Table 2 demonstrate reasonable agreement between \(-\frac{1}{3}\) bar tension and direct field capacity measurements for the subsoil of all three profiles. However, \(-\frac{1}{3}\) bar tensions do not reproduce field capacity for the surface 10 cm of Tindall and Emu profiles, and the upper 50 cm of the Blain profile.

Infiltration rates over a period of 4 hours flooding are presented in Figure 2. The initial infiltration rate for the surface horizon of the Blain soil is far greater than that for the Tindall and Emu soils, but is reduced by half after a very short period of continuous water supply. After prolonged water
Table 2. Physical characteristics of three red earth soil profiles

<table>
<thead>
<tr>
<th>Soil and depth (cm)</th>
<th>Particle size*</th>
<th>Mineralogy of clay fraction **</th>
<th>Bulk density (g/cm³)</th>
<th>Gravimetric moisture content (-15 bar -1/3 bar, field capacity)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CS FS SI Cl</td>
<td>K I H V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TINDALL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td>21 44 11 22</td>
<td>40-50 30-40 10-20</td>
<td>1.38</td>
<td>7.6 13.8 16.2</td>
</tr>
<tr>
<td>10-20</td>
<td>19 39 8 33</td>
<td>40-50 30-40 10-20</td>
<td>1.50</td>
<td>9.9 15.1 15.3</td>
</tr>
<tr>
<td>20-30</td>
<td>16 37 7 40</td>
<td>50-65 30-40 10-20</td>
<td>1.62</td>
<td>12.2 16.4 16.7</td>
</tr>
<tr>
<td>30-40</td>
<td>15 34 6 42</td>
<td>50-65 30-40 10-20</td>
<td>1.58</td>
<td>12.5 16.8 17.3</td>
</tr>
<tr>
<td>40-50</td>
<td>15 33 5 44</td>
<td>50-65 30-40 10-20</td>
<td>1.55</td>
<td>12.8 17.2 18.0</td>
</tr>
<tr>
<td>50-60</td>
<td>15 32 5 45</td>
<td>50-65 30-40 10-20</td>
<td>1.56</td>
<td>13.2 17.6 18.2</td>
</tr>
<tr>
<td>60-70</td>
<td>14 31 5 47</td>
<td>50-65 30-40 10-20</td>
<td>1.56</td>
<td>13.7 18.0 18.4</td>
</tr>
<tr>
<td>70-80</td>
<td>13 31 6 48</td>
<td>50-65 30-40 10-20</td>
<td>1.57</td>
<td>13.3 18.4 18.6</td>
</tr>
<tr>
<td>80-90</td>
<td>13 30 6 48</td>
<td>50-65 30-40 10-20</td>
<td>1.58</td>
<td>13.0 18.8 18.8</td>
</tr>
<tr>
<td>90-100</td>
<td>12 30 6 48</td>
<td>50-65 20-30 10-20</td>
<td>1.59</td>
<td>12.7 18.5 18.8</td>
</tr>
<tr>
<td>BLAIN</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td>24 68 3 5</td>
<td>50-65 20-30 20-30</td>
<td>1.48</td>
<td>3.3 6.4 9.5</td>
</tr>
<tr>
<td>10-20</td>
<td>23 67 3 7</td>
<td>50-65 20-30 20-30</td>
<td>1.57</td>
<td>3.2 6.0 10.9</td>
</tr>
<tr>
<td>20-30</td>
<td>21 67 3 7</td>
<td>50-65 20-30 20-30</td>
<td>1.66</td>
<td>3.2 5.1 11.3</td>
</tr>
<tr>
<td>30-40</td>
<td>19 65 5 9</td>
<td>50-65 10-20 20-30</td>
<td>1.69</td>
<td>5.6 8.1 14.5</td>
</tr>
<tr>
<td>40-50</td>
<td>23 52 6 18</td>
<td>50-65 10-20 20-30</td>
<td>1.72</td>
<td>7.9 11.2 15.4</td>
</tr>
<tr>
<td>50-60</td>
<td>18 50 2 28</td>
<td>50-65 10-20 20-30</td>
<td>1.69</td>
<td>10.3 13.8 16.6</td>
</tr>
<tr>
<td>60-70</td>
<td>18 41 2 39</td>
<td>50-65 10-20 20-30</td>
<td>1.67</td>
<td>12.8 16.5 19.0</td>
</tr>
<tr>
<td>70-80</td>
<td>17 37 2 41</td>
<td>50-65 10-20 20-30</td>
<td>1.65</td>
<td>13.7 17.5 19.2</td>
</tr>
<tr>
<td>80-90</td>
<td>14 38 3 43</td>
<td>50-65 10-20 20-30</td>
<td>1.63</td>
<td>14.7 18.5 19.9</td>
</tr>
<tr>
<td>90-100</td>
<td>13 31 2 52</td>
<td>65-80 10-20 20-30</td>
<td>1.62</td>
<td>15.7 21.2 21.3</td>
</tr>
<tr>
<td>EHU</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td>11 64 15 10</td>
<td>20-30 50-65 10-20</td>
<td>1.48</td>
<td>7.2 16.2 19.2</td>
</tr>
<tr>
<td>10-20</td>
<td>7 63 13 17</td>
<td>20-30 50-65 10-20</td>
<td>1.54</td>
<td>7.8 16.1 17.7</td>
</tr>
<tr>
<td>20-30</td>
<td>6 50 12 22</td>
<td>10-20 50-65 20-30</td>
<td>1.61</td>
<td>8.5 16.9 17.5</td>
</tr>
<tr>
<td>30-40</td>
<td>6 53 12 27</td>
<td>10-20 50-65 20-30</td>
<td>1.64</td>
<td>9.4 16.6 17.8</td>
</tr>
<tr>
<td>40-50</td>
<td>5 53 12 30</td>
<td>10-20 50-65 20-30</td>
<td>1.67</td>
<td>10.3 17.1 18.1</td>
</tr>
<tr>
<td>50-60</td>
<td>5 50 9 34</td>
<td>10-20 50-65 20-30</td>
<td>1.70</td>
<td>10.7 17.9 18.3</td>
</tr>
<tr>
<td>60-70</td>
<td>4 50 12 33</td>
<td>10-20 50-65 20-30</td>
<td>1.67</td>
<td>11.1 18.8 19.6</td>
</tr>
<tr>
<td>70-80</td>
<td>4 50 15 32</td>
<td>10-20 50-65 20-30</td>
<td>1.65</td>
<td>10.9 19.5 19.9</td>
</tr>
<tr>
<td>80-90</td>
<td>7 53 18 22</td>
<td>10-20 50-65 20-30</td>
<td>1.66</td>
<td>10.6 20.2 20.2</td>
</tr>
<tr>
<td>90-100</td>
<td>6 49 24 22</td>
<td>10-20 50-65 20-30 1-5</td>
<td>1.68</td>
<td>11.0 22.8 22.8</td>
</tr>
</tbody>
</table>

* Particle sizes
  - Coarse sand: 2.00 - 0.200 mm
  - Fine sand: 0.20 - 0.020
  - Silt: 0.02 - 0.002
  - Clay: <0.002

** K - Kaolinite
  - I - Illite
  - H - Haematite
  - V - Vermiculite
application, the infiltration rate for the Blain soil remained high relative to the other two soils.

Figure 2. Infiltration rates into three initially dry soils
The variation in moisture holding capacity with depth in each soil is demonstrated in Figure 3. Using the flood wetting up technique, the Tindall profile retains 7.67 cm of water per metre depth, between the moisture tensions of -1/3 and -15 bar. The Blain profile retains only 5.56 cm of water in the same depth, and is characterized by extremely low retention values for the sandy A horizon. Water retained in the subsoil of the Blain increased markedly with depth to approach that held by the Tindall soil at a depth of 90 to 100 cm. Over a metre depth the Emu profile retained the highest amount of 13.52 cm of water.

Figure 3. Variation in moisture holding capacity with depth

Complete moisture retention curves for three selected depths of each soil are presented in Figure 4. Since samples were wet up under a tension of 5 cm water, results are not directly comparable with those in Table 2 and Figure 3.
Figure 4. Moisture retention curves for three red earth soils

For the 0 to 10 cm depth (Figure 4a) the Blain soil clearly retains far less water than the Tindall and Emu soils over the entire tension range. With increasing depth (Figure 4b and 4c) this difference is reduced to the extent that 90 to 100 cm depths of all three soils have similar retention characteristics between -0.5 and -15 bar.

Chemical Characteristics

Analytical data for each of the soils to a depth of one metre are presented in Table 3.
### TABLE 3  
Analytical data for 3 representative profiles before cropping.

<table>
<thead>
<tr>
<th>Soil and Depth (cm)</th>
<th>pH</th>
<th>Ca (ppm)</th>
<th>Mg (ppm)</th>
<th>K (ppm)</th>
<th>Na (ppm)</th>
<th>Organic C (mole/l)</th>
<th>Available (ppm)</th>
<th>Exchangeable Cations (meq/100g)</th>
<th>Calcium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Sodium (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.1</td>
<td>0.023</td>
<td>0.463 0.015</td>
<td>3.55 0.03 0.02</td>
<td>0.49 0.01 0.0</td>
<td>3.10 0.02 0.0</td>
<td>1.10 0.01 0.0</td>
</tr>
<tr>
<td>6-10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.9</td>
<td>0.021</td>
<td>0.781 0.015</td>
<td>6.2 22.0 0.05</td>
<td>0.18 0.01 0.0</td>
<td>2.0 0.01 0.0</td>
<td>0.2 0.01 0.0</td>
</tr>
<tr>
<td>10-15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.0</td>
<td>0.210</td>
<td>0.140 0.015</td>
<td>1.4 15.0 0.09</td>
<td>0.38 0.01 0.0</td>
<td>2.1 0.01 0.0</td>
<td>0.2 0.01 0.0</td>
</tr>
<tr>
<td>15-20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.1</td>
<td>0.200</td>
<td>0.208 0.015</td>
<td>2.0 0.02 0.0</td>
<td>0.38 0.01 0.0</td>
<td>2.2 0.01 0.0</td>
<td>0.2 0.01 0.0</td>
</tr>
<tr>
<td>20-30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.6</td>
<td>0.100</td>
<td>0.140 0.015</td>
<td>1.0 0.01 0.0</td>
<td>0.38 0.01 0.0</td>
<td>2.2 0.01 0.0</td>
<td>0.2 0.01 0.0</td>
</tr>
<tr>
<td>30-40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.4</td>
<td>0.021</td>
<td>0.333 0.015</td>
<td>0.9 0.01 0.0</td>
<td>0.38 0.01 0.0</td>
<td>2.2 0.01 0.0</td>
<td>0.2 0.01 0.0</td>
</tr>
<tr>
<td>40-50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.0</td>
<td>0.020</td>
<td>0.145 0.015</td>
<td>0.9 0.01 0.0</td>
<td>0.38 0.01 0.0</td>
<td>2.2 0.01 0.0</td>
<td>0.2 0.01 0.0</td>
</tr>
<tr>
<td>50-60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.4</td>
<td>0.021</td>
<td>0.40 0.015</td>
<td>0.9 0.01 0.0</td>
<td>0.38 0.01 0.0</td>
<td>2.2 0.01 0.0</td>
<td>0.2 0.01 0.0</td>
</tr>
</tbody>
</table>

Analytical data for 3 representative profiles before cropping.
Generally, per cent chloride, total soluble salts and exchangeable sodium levels are low throughout, with an acid soil reaction trend in all three profiles. Surface horizons are 50 to 80 per cent base saturated with calcium as the dominant exchangeable cation.

Surface organic carbon levels vary from a low 0.9 per cent for the Blain to 1.7 per cent for the Emu soil. The organic carbon level in the Emu soil is maintained at 0.4 to 0.5 per cent down to a metre depth in contrast to the Tindall and Blain soils where the organic carbon content is reduced markedly with depth. Organic nitrogen values are very low for all three soils. Values range from 0.04 to 0.09 per cent for the surface depth of Blain and Emu soils respectively. A marked reduction in organic nitrogen occurs below the A₁ horizon for all three soil profiles.

All three red earths have low levels of total and bicarbonate soluble phosphorus, but seem better supplied with potassium.

DISCUSSION

Soil morphology, particle size distributions, clay mineral constituents and certain soil chemical characteristics support hypotheses that the three soils have been derived from entirely different lithological materials.

The proportion of constituent clay minerals varies between soils. In Tindall and Blain soils the proportion of kaolinite to illite is approximately 2 : 1 and 4 : 1 respectively. A reverse proportion of 1 : 3 kaolinite to illite occurs in the Emu soil, which seems to be related to its micaceous siltstone parent material.
Initial infiltration rates for all three red earths are high, in particular the Blain soil, indicating the high sorptivity of such surface soils when in the dry condition. Long term infiltration measurements of this kind provide an estimation of the saturated hydraulic conductivity, which for these soils is relatively constant after 20 minutes flooding. This property reflects a very stable pore size distribution within each soil. Final steady state infiltration rates indicate that the saturated hydraulic conductivity for the Blain surface soil is more than six times that of the Tindall and Emu soils. High infiltration rates and storage of water at depth have also been observed by Arndt, Phillips and Norman (1963) on a Blain soil near Katherine, N.T. These authors also reported that soil water seemed to remain available at depth in Blain soils for a longer time during dry periods when compared to the loamy red earths of the same area. One explanation could be that the sandy A horizon of the Blain tends to retard the movement of liquid phase water from the subsoil to the soil surface due to a higher proportion of large soil pores.

The low saturated hydraulic conductivity of both Tindall and Emu soils indicates the likelihood of high run-off losses and soil erosion during periods of continuous rainfall. Surface sealing of other loamy red earth soils following rainfall has been recognised as an important soil physical problem, particularly under continuous cropping (Arndt, 1961). This hazard may even be more serious on Emu soils due to their higher proportion of silt sized particles. Deep cultivation of such soils during the late dry season and early wet season may permit deeper penetration of early wet season rains (Phillips, 1959), hence utilizing their moisture holding capacities more effectively. The return of crop residues may also reduce the effect of surface
sealing (Arndt, 1961), and at the same time maintain organic carbon and nitrogen reserves.

The moisture holding capacity between \(-\frac{1}{3}\) and \(-15\) bar differs greatly between soils. The value of 7.67 cm per m for the Tindall profile is similar to that published earlier for a loamy Tippera red earth from the same region (Slatyer, 1955). However, the retention value for the Blain soil of 5.56 cm per m is considerably higher than that reported earlier for a Blain profile from a different location (Arndt, Phillips and Norman, 1963). Relatively high moisture holding capacities such as that for the Emu soil (13.52 cm per m) have not been reported previously for red earths of this region. This feature of the Emu soil seems chiefly associated with the high proportions of fine sand and silt sized particles and the resultant pore size distribution.

Available soil moisture in the Blain surface 10 cm is retained between \(-\frac{1}{3}\) and \(-2\) bar approximately, with the consequence that this surface horizon will be extremely droughty, as drainage and evaporation deplete this reservoir rapidly. This limitation to seedling establishment under dry conditions has also been observed by Arndt, Phillips and Norman (1963) and Fisher (1971). Cropping of Blain soils may also incur problems of soil erosion and loss of organic nitrogen reserves following rapid mineralization and leaching of nitrate nitrogen from the root zone (Wetselaar, 1962; Arndt, Phillips and Norman, 1963). Surface horizons of Tindall and Emu soils differ in that available soil moisture is retained between \(-\frac{1}{3}\) and \(-4\) bar, and \(-\frac{1}{3}\) and \(-8\) bar respectively.

Base exchange capacities of Tindall and Emu soils are similarly low but lie within the range of reported values for other loamy red earths of the area. The similarity in this
property between these soils is unusual when one considers the difference in clay mineral constituents. Fixation of potassium by illite in the Emu soil may explain the apparently low base exchange capacity of this soil. The Blain soil exhibits extremely low base exchange capacities.

The Tindall soil seems adequately supplied with calcium throughout the profile, whereas Blain and Emu profiles are quite low in exchangeable calcium, particularly at depth. Mean exchangeable Ca to Mg ratios for the Tindall and Emu soils are similar, at 2.7:1 and 2.9:1 respectively. The Blain soil is not as well supplied with exchangeable magnesium, with a mean exchangeable Ca : Mg ratio of 4.4:1. The Tindall and in particular the Emu soil seem adequately supplied with exchangeable potassium. However, a potential deficiency exists for the Blain soil where exchangeable potassium values are less than 0.2 m.e. per 100 g in most depths below the surface 5 cm.

All three red earths have low levels of total and bicarbonate extractable phosphorus, particularly the Blain profile, indicating that phosphorus deficiencies are likely.

Total and bicarbonate soluble potassium values indicate that the three red earths are considerably better supplied with potassium than phosphorus. The Emu soil in particular has quite high total potassium values as a result of weathering of the micaeous siltstone parent material, and the predominance of the clay mineral illite. Much of the potassium in this soil is chemically fixed by illite as indicated by the comparatively low exchangeable potassium values in relation to total and bicarbonate soluble potassium.
Total sulphur values for the surface of all three red earths lie within the range reported by McLachlan (1974), for acidic Australian soils. For the surface horizon C : N : S ratios are 110 : 6 : 1.5, 90 : 4 : 1.3 and 170 : 9 : 1.1 for Tindall, Blain and Emu soils respectively. Such ratios indicate higher sulphur status when compared to other red earth soils of north Queensland (Probert, 1974; Isbell and Smith, 1976; Isbell, Jones and Gillman, 1976). The surface horizons of Tindall and Emu soils have appreciable amounts of bicarbonate extractable sulphur, however not all of the sulphur in this fraction is available for plant uptake.

Organic carbon and nitrogen values for the surface horizons of all three soils are low but are consistent with reported values for other red earths of the area.

The above results are drawn from relatively few sites hence conclusions have been broad rather than specific. The results highlight the need to study a wide range of red earth soils over the entire Daly Basin with particular emphasis on certain soil physical characteristics. This information is necessary prior to recommending their suitability for crop or pasture production, and to estimate their long term stability.

ACKNOWLEDGEMENTS

I would like to thank Mr. A.D.L. Hooper and Mr. J.M. Aldrick for their guidance and comments on the manuscript, and Mr. R.L. Henderson for the preparation of illustrations. I am indebted to several officers of the Division of Soils, C.S.I.R.O., in particular Mr. P. Menage, Mr. J.T. Hutton and the late A.R.P. Clarke who carried out many of the chemical analyses.
REFERENCES


2. Leaching of nitrate under grain sorghum in a tropical monsoonal climate

K.J. Day
SUMMARY

This paper reports rates of leaching and depths of accumulation of nitrate applied to three red earth soils (Tindall, Blain and Emu) in a tropical monsoonal climate. All three soils were cropped to grain sorghum.

Ammonium nitrate at a rate of 112 kg nitrogen per ha was placed in rows 18 cm apart to a depth of 7 cm. Soil sampling to a depth of 180 cm took place at various growth stages on plots receiving fertilizer and on an equal number left unfertilized.

During the sorghum growing season leaching displaced nitrate to between 45 and 105 cm in the Tindall and between 60 and 165 cm in the Emu. In the coarser textured Blain soil, leaching displaced nitrate to between 75 and 180 cm during the same growth period.

Using a water balance model, an attempt has been made to relate such measurements to rainfall percolating the soil profile which is strongly influenced by both soil physical characteristics and rainfall distribution.

Leaching of nitrate was very rapid through the sandy A horizon of the Blain, with a rate of 5 cm displacement per cm of percolating rainfall measured during a period of intermittent low intensity rainfall. However, apparent leaching rates through the clay B horizon of the Blain were of the same order (1.85 to 3.1 cm per cm of percolating rainfall) as leaching rates measured in the loamy Tindall and Emu soils during periods of consistent heavy rainfall.
INTRODUCTION

The downward movement of nitrate and subsequent nitrogen loss to crops has been most intensively studied in tropical and subtropical regions of the world with a high seasonal rainfall distribution. In medium and fine textured soils under bare fallow, the application of less than 1 200 mm of water usually as natural rainfall has resulted in nitrate accumulation at depths between 40 and 120 cm and in very coarse textured soils to 150 cm and further (Mills, 1953; Wetselaar, 1962a; Wild, 1972; Black and Waring, 1976a). Such deep displacement of both naturally occurring and applied nitrate seems to be little affected by shallow rooting crops (Mills, 1953; Jewitt, 1956; Wetselaar, 1962b; Jones, 1975; Black and Waring, 1976a).

Field evidence in highly permeable soils indicates that applied ammonium in that chemical form is not displaced below a depth of 40 cm (Wetselaar, 1962b; Black and Waring, 1976a).

In the tropical monsoonal region of the Northern Territory, infrequent periods of rainfall exceed evapotranspiration requirements yet the importance of leaching as a nitrogen loss mechanism under a cropping regime is not well understood. Earlier studies related nitrate displacement to incident rainfall when fertilizer was broadcast on soils in the bare fallow condition.

This paper reports the results of a field sampling program during one particular wet season. The apparent rate of displacement and depth of accumulation of nitrate under grain sorghum are compared between three widely occurring red earth soils with different physical characteristics. An attempt has been made to relate such measurements to rainfall percolating through the soil profile as well as total incident rainfall.
METHODS AND ANALYSIS

Differences in the morphological, physical and chemical characteristics of the three red earth soils, the geographical location of the field sites and features of the climate of the region are described in the previous paper of this series. The spatial distribution of the three sites has resulted in the Tindall site near Katherine experiencing an average annual rainfall of 889 mm, while the Blain and Emu sites on Tipperary Station to the north experience an annual average of 1143 mm rainfall.

From a large fertilizer factorial design, plots receiving no nitrogen (No) and 112 kg nitrogen per ha (N3) as ammonium nitrate were selected for soil sampling. All sampled plots received 56 kg of phosphorus per ha. Results presented in this paper are taken from the sampling program during the 1972-73 wet season. The Tindall red earth was sampled in greater detail using three replicate plots of each nitrogen treatment. Only one plot of each nitrogen treatment was sampled on the Blain and Emu sites.

All fertilizer was drilled with a tined implement to a depth of 7 cm, in rows 18 cm apart, prior to sowing with the same machine. Grain sorghum (Sorghum bicolor Dekalb E57) was sown at a rate of 9 kg seed per ha in rows 36 cm apart, ensuring that each plant row coincided with every second fertilizer drill row. Plot size was 61 m by 3.3 m which permitted eight plant rows lengthways within the plot perimeter. Terminology applied to the various sorghum growth stages are those defined by Vanderlip and Reeves (1972). Total nitrogen in plant material and soil was determined by micro-Kjeldahl digestion, distillation and titration.
At each sampling during the growing season, five soil cores 5 cm in diameter were taken from random positions within the plant rows of each plot. Sampling was undertaken to a depth of 105 cm with the exception of deeper pre-season sampling before the onset of wet season rains and during the later stages of plant growth. Soil cores were segmented into 15 cm lengths and identical depths bulked for each plot. Subsampling took place immediately after collection.

On all sampled depths, nitrate nitrogen was extracted with distilled water (1 : 5 soil-water ratio) shaken for 30 minutes and determined using the nitrate ion electrode method of Myers and Paul (1968). Earlier experience with this method demonstrated that the use of an extractant anion did not improve nitrate recovery. Extracts were refrigerated but unfiltered prior to determination. As an added precaution to minimize bacterial activity, a preservative phenyl mercuric acetate (0.1 per cent W/V solution) was added at the rate of 1 ml per litre of the distilled water used for extraction purposes.

Ammonium nitrogen was extracted with 2N-KCL (1 : 5 soil-solution ratio) shaken for 60 minutes, and determined by the colorimetric phenate method after Weatherburn (1967) and Beecher and Whitten (1970). Depths 0 to 15 and 15 to 30 cm only were analysed for ammonium nitrogen.

BASIC ASSUMPTIONS

Several assumptions regarding components of the nitrogen cycle have been made in this work. Denitrification losses of leached nitrate in such well drained red earths were assumed negligible (Wetselaar, Jakobsen and Chaplin, 1973), as were the amounts of mineral nitrogen added to the soil from
rainwater (Wetselaar and Hutton, 1963). Nitrate leaching rates measured in this work must be regarded as apparent rather than actual, since the concentration and movement of nitrate is influenced by several major plant-soil processes.

To estimate the amount of percolating rainfall during each sampling interval, the soil moisture model Cropeval similar to that described by Fitzpatrick and Nix (1969) for summer grown dryland grain sorghum was used. Input data were daily rainfall on site and district pan evaporation accumulated as weekly totals. A weekly account of available soil moisture and actual evapotranspiration were provided by this model. Details on the use of this soil moisture data, together with measured available soil moisture values to estimate run-off and percolating rainfall are given in appendix 1.

RESULTS AND DISCUSSION

Recovery of applied ammonium

Sampling the day after nitram was applied to the Tindall soil resulted in the recovery of 84 per cent of applied ammonium in that form (Table 1), due mainly to sampling inaccuracy. The sampling point may not have corresponded exactly with the centre of the fertilizer drill row at the time when fertilizer would have been concentrated in a very small soil volume. Most of the applied ammonium was retained in the surface 15 cm depth of the Tindall, with evidence of displacement of a small amount into the 15 to 30 cm depth interval four weeks after application (6 Feb. 1973). Nitrification of applied ammonium in this soil seemed to be complete 54 days after application.
From the 0 to 30 cm depth of the Blain soil only 21 per cent of applied ammonium was recovered in that form when sampled 12 days after fertilizer application (Table 1). By this time a considerable amount of applied ammonium had been displaced into the 15 to 30 cm depth interval. Such a low recovery cannot be explained readily from these results, but an identical sampling problem to that on the Tindall may exist, together with probable displacement of ammonium beyond 30 cm and very rapid nitrification of applied ammonium in the Blain. Very little applied ammonium was detected in the 0 to 30 cm depth of the Blain 35 days after application (9 Feb. 1973).

For the Emu soil only 14 per cent of applied ammonium was recovered in that form from the 0 to 30 cm depth, 12 days after fertilizer application (Table 1). Three possible mechanisms are likely to account for such a low recovery: (i) rapid nitrification of applied ammonium; (ii) ammonium fixation by the dominant clay mineral illite; (iii) sampling inaccuracy early in the growing season as discussed above. Early leaching of ammonium below a depth of 30 cm in the Emu soil is not as likely as it is in the case of the Blain. Applied ammonium could not be detected in the 0 to 30 cm depth of the Emu, 35 days after fertilizer application (8 Feb. 1973).

Native nitrate displacement

The distribution of native nitrate in Tindall and Blain soils prior to opening rains (Figure 1a, 2a) reflects leaching and subsoil accumulation of nitrate during the previous wet season. At this sampling, nitrate concentration peaks were found at 40 to 120 cm in the control plots of Tindall and Blain soils respectively. In contrast the Emu profile was almost depleted of native nitrate presumably due to leaching during the previous wet season (Figure 3a).
Table 1. Ammonium nitrogen recovered from control (No) and fertilized (N3) plots of three soils cropped to grain sorghum

<table>
<thead>
<tr>
<th>Soil</th>
<th>Nitrogen recovered</th>
<th>Sampling depth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-15 cm</td>
<td>15-30 cm</td>
</tr>
<tr>
<td></td>
<td>No (kg/ha)</td>
<td>N3 (kg/ha)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TIN DALL SOIL</td>
<td>N applied 10 Jan. 1973</td>
<td>Sampling date</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 Jan. 1973</td>
<td>22</td>
<td>60*</td>
</tr>
<tr>
<td>6 Feb. 1973</td>
<td>24</td>
<td>53*</td>
</tr>
<tr>
<td>5 Mar. 1973</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>5 Apr. 1973</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>28 Apr. 1973</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>BLAIN SOIL</td>
<td>N applied 5 Jan. 1973</td>
<td>Sampling date</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17 Jan. 1973</td>
<td>47</td>
<td>49</td>
</tr>
<tr>
<td>22 Mar. 1973</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>9 May 1973</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>ENU SOIL</td>
<td>N applied 4 Jan. 1973</td>
<td>Sampling date</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16 Jan. 1973</td>
<td>26</td>
<td>32</td>
</tr>
<tr>
<td>8 Feb. 1973</td>
<td>23</td>
<td>24</td>
</tr>
<tr>
<td>15 Mar. 1973</td>
<td>24</td>
<td>17</td>
</tr>
<tr>
<td>16 Apr. 1973</td>
<td>6</td>
<td>7</td>
</tr>
</tbody>
</table>

* No and N3 significantly different at P = 0.05 using least significant differences calculated on logarithmic transformed means (ppm)
With the onset of wet season rains, mineralization of nitrogen provided a large contribution to the native nitrate status of all three soils (Figure 1b, 2b, 3b). Concentrations of native nitrate nitrogen equivalent to 138 kg in the Tindall, 77 kg in the Blain and 102 kg in the Emu per ha were measured to a depth of 105 cm at this sampling close to sowing, and little was leached below 60 cm.

After sowing, 154 mm of percolating rainfall (Table 2) caused rapid displacement of native nitrate in the Tindall soil. At this sampling which corresponded to floral initiation (Figure 1c), native nitrate was largely depleted from the upper 30 cm of the Tindall with a peak accumulation at a depth of 65 cm. Further sampling at three later growth stages on the Tindall soil added little information on the displacement of native nitrate since concentrations were reduced greatly and remained low throughout the grain filling period. At crop maturity, only 38 kg per ha of native nitrate nitrogen remained in the Tindall to a depth of 150 cm.

For the Blain soil, considerable displacement of native nitrate had already occurred from the 0 to 30 cm depth with a concentration peak at 39 cm when measured 12 days after sowing (Figure 2b). At the floral initiation growth stage, (9 Feb. 1973) the upper 90 cm of the Blain soil profile was largely depleted of native nitrate following a further 256 mm of percolating rainfall (Table 2, Figure 2c). Further sampling to greater depths demonstrated very reduced concentrations of native nitrate. An equivalent of 31 kg per ha of nitrate nitrogen remained at crop maturity to a depth of 180 cm in the Blain control plot.
Figure 1. Total nitrate concentrations in a Tindall red earth under grain sorghum. Regression coefficients for each distribution curve and percolating rainfall between samplings shown in parenthesis. Cross hatched areas of the histograms represent applied nitrate.
Figure 2. Total nitrate concentrations in a Blain red earth under grain sorghum. Regression coefficients for each distribution curve and percolating rainfall between samplings shown in parenthesis. Cross hatched areas of the histograms represent applied nitrate.
Figure 3. Total nitrate concentrations in an Emu red earth under grain sorghum. Regression coefficients for each distribution curve and percolating rainfall between samplings shown in parenthesis. Cross hatched areas of the histograms represent applied nitrate.
By the floral initiation growth stage on the Emu soil (8 Feb. 1973), a total of 324 mm of percolating rainfall resulted in the leaching of native nitrate below a depth of 45 cm, with a peak accumulation at 75 cm (Table 2, Figure 3c). Later samplings demonstrated a greatly reduced concentration of native nitrate, with the equivalent of 24 kg per ha of nitrate nitrogen remaining in the Emu control plot to a depth of 165 cm.

Applied nitrate displacement

The regression coefficients in Figures 1, 2 and 3 and the standard errors in Figure 1 refer only to total nitrate concentrations measured in plots receiving fertilizer.

The recovery of 82 per cent of applied nitrate one day after the application of fertilizer to the Tindall soil was almost identical to the recovery level for applied ammonium at the same sampling. Nitrate was contained within the surface 15 cm (Figure 1b). The failure to recover all applied nitrate provides further evidence of the early sampling inaccuracy discussed earlier. Once plants emerged, the problem of precisely locating the fertilizer drill row did not occur, as substantiated by almost complete recovery (98 per cent) of applied nitrogen at the following sampling (6 Feb. 1973).

During the four weeks after sowing on the Tindall, 154 mm of percolating rainfall caused the displacement of the peak nitrate concentration to 38 cm (Figure 1c). At this sampling which corresponded to floral initiation (6 Feb. 1973), 66 per cent of applied nitrogen was recovered in the nitrate form, mainly between the depths of 15 and 45 cm.
More intermittent rain of low intensity fell during the succeeding four weeks to the anthesis growth stage (5 Mar. 1973) with the consequence that negligible run-off occurred. At this sampling, applied nitrate was found to be largely depleted from the 0 to 30 cm depth of the Tindall (Figure 1d) following 45 mm of percolating rainfall. During this period the peak nitrate concentration was displaced to 45 cm and 80 per cent of applied nitrogen was recovered in the nitrate form, nitrification of applied ammonium being complete at this sampling time.

During grain filling, a further 96 mm of percolating rainfall displaced applied nitrate to between 45 and 105 cm and probably deeper, with a peak nitrate concentration at 75 cm (Figure 1e). Recovery of applied nitrogen to 105 cm was reduced to 50 per cent at this sampling, presumably due to deeper displacement as indicated by the shape of the nitrate distribution curve.

Between samplings on the 5th and 28th April 1973, no rain fell on the Tindall site, resulting in a broader nitrate distribution curve and accumulation of nitrate mainly between 30 and 90 cm (Figure 1f). Recovery of applied nitrate at this sampling was reduced further to 38 per cent. During this period of high evapotranspirational demand, capillary movement of soil water may be operative in causing upward movement of nitrate. The lower limit for such a mechanism to operate was previously thought to be 45 cm for a similar soil in this area, but in the bare fallow condition (Wetselaar, 1961).

The Blain site was first sampled 12 days after fertilizer application with the resultant recovery of 64 per cent of applied nitrogen as nitrate between the depths of 15 and 30 cm (Figure 2b). Leaching was very effective in this sandy A horizon with the addition of only 31 mm of percolating rainfall during this period (Table 2).
Table 2. Rainfall components and apparent leaching rates for nitrate applied to three soils under grain sorghum

<table>
<thead>
<tr>
<th>Sampling Intervals</th>
<th>Total rainfall between samplings (mm)</th>
<th>Percolating rainfall (mm)</th>
<th>Depth of movement of the nitrate concentration peak (cm)</th>
<th>Apparent downward movement of total percolating rainfall (cm/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TINDALL SOIL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N applied</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 Jan. 1973</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 Jan. 1973</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 Jan. - 6 Feb. 1973</td>
<td>315</td>
<td>154</td>
<td>31.0</td>
<td>0.98</td>
</tr>
<tr>
<td>7 Feb. - 5 Mar. 1973</td>
<td>116</td>
<td>45</td>
<td>7.0</td>
<td>0.60</td>
</tr>
<tr>
<td>6 Mar. - 5 Apr. 1973</td>
<td>224</td>
<td>96</td>
<td>30.0</td>
<td>1.34</td>
</tr>
<tr>
<td>6 Apr. - 28 Apr. 1973</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>BLAIR SOIL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N applied</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Jan. 1973</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17 Jan. 1973</td>
<td>46</td>
<td>31</td>
<td>15.5</td>
<td>3.37</td>
</tr>
<tr>
<td>18 Jan. - 9 Feb. 1973</td>
<td>334</td>
<td>256</td>
<td>60.5</td>
<td>1.81</td>
</tr>
<tr>
<td>10 Feb. - 22 Mar. 1973</td>
<td>299</td>
<td>179</td>
<td>57.0</td>
<td>1.57</td>
</tr>
<tr>
<td>23 Mar. - 9 May 1973</td>
<td>65</td>
<td>22</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>EMU SOIL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N applied</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Jan. 1973</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16 Jan. 1973</td>
<td>93</td>
<td>44</td>
<td>60.0</td>
<td>1.12</td>
</tr>
<tr>
<td>17 Jan. - 8 Feb. 1973</td>
<td>443</td>
<td>280</td>
<td>30.0</td>
<td>0.98</td>
</tr>
<tr>
<td>9 Feb.</td>
<td>16 Apr. 1973</td>
<td>306</td>
<td>104</td>
<td>30.0</td>
</tr>
</tbody>
</table>
During the next three weeks to the 9th February 1973, which corresponded to floral initiation, the peak nitrate concentration was displaced to 83 cm (Figure 2c) following 256 mm of percolating rainfall on the Blain. Most applied nitrate had been removed from the 0 to 45 cm depth and this sampling to only 105 cm did not permit an evaluation of displacement below that depth. Deeper sampling to 150 cm at the anthesis stage of crop growth again did not satisfactorily indicate the maximum extent of nitrate displacement (Figure 2d) following a further 179 mm of percolating rainfall. At this growth stage, applied nitrate had been completely removed from the upper 90 cm of the soil profile.

At crop maturity (9 May 1973) on the Blain soil, after a further addition of 22 mm of percolating rainfall, deep sampling indicated a peak accumulation of nitrate at 140 cm (Figure 2e). This sampling was preceded by 21 days without rain and recovered 64 per cent of applied nitrogen in the nitrate form mainly between the depths of 90 and 180 cm.

Soil sampling to recover nitrogen applied to the Emu soil has not produced conclusive results, and has posed some questions which require detailed investigations to answer. As discussed in the previous paper in this series, undulating layers of partly weathered micaeous siltstone occur in the Emu soil, usually at depths of less than one metre, overlying silicified limestone. The depth at which limestone was encountered in the plot which received nitrogen fertilizer varied greatly, and hindered the bulking of identical depths. Dipping of the siltstone layers is thought to result in variable drainage characteristics over the site thus allowing deeper leaching of nitrate at some locations, and concentration at others. As a result the depth of peak accumulation of applied nitrate and apparent nitrate leaching
rates were difficult to ascertain, and only three samplings are discussed.

Sampling on the Emu site 12 days after fertilizer application recovered 62 per cent of applied nitrogen in the nitrate form. During this period 44 mm of percolating rainfall caused displacement of some applied nitrate to a depth of 45 cm, but most was still contained in the 0 to 30 cm depth (Figure 3b).

At the floral initiation growth stage (8 Feb. 1973) sampling to a depth of 105 cm recovered only 27 per cent of applied nitrogen in the nitrate form, mainly between the depths of 60 and 90 cm (Figure 3c). The total of 324 mm of percolating rainfall which occurred since fertilizer application (4 Jan. - 8 Feb. 1973) resulted in the removal of applied nitrate from the upper 60 cm of the Emu soil profile, a peak accumulation at 67 cm and probable leaching of nitrate below the maximum sampling depth.

Sampling at crop maturity (16 Apr. 1973) recovered an unusually large amount of nitrate, in fact far in excess of that applied. This can only be explained by the effect of subsoil layering, which may tend to concentrate nitrate by lateral movement from adjacent rows, as well as downward displacement as leaching progresses. During this very long sampling interval (9 Feb. - 16 Apr. 1973) a total of 104 mm of percolating rainfall resulted in the displacement of the peak nitrate concentration to 97 cm in the Emu soil (Figure 3d).

Any reduction in the recovery of applied nitrogen in the nitrate form from all three soils as sampling progressed may be due in part to (i) crop uptake, together with (ii) leaching of nitrate below the maximum sampling depth and (iii) gradual lateral movement of nitrate away from the point of application.
The importance of crop nitrogen uptake is discussed in a section to follow, nevertheless in the Tindall soil the continued reduction in applied nitrate recovery adds weight to the importance of lateral movement, together with possible downward displacement beyond 105 cm during early grain filling. On the other extreme, deep nitrate displacement beyond the maximum sampling depth seems to be the dominant mechanism in lowering nitrate recovery from the Blain soil profile.

**Apparent nitrate leaching rates**

Rainfall components and apparent leaching rates for applied nitrate during the various sampling intervals are given in Table 2. For the Tindall soil, apparent leaching rates in terms of both total and percolating rainfall varied primarily with rainfall intensity and distribution. Where groups of high intensity rainfall occurred during the sampling interval (12 Jan. - 6 Feb. 1973 and 6 Mar. - 5 Apr. 1973) apparent leaching rates were of the order of 1 to 1.3 cm per cm of total rainfall and 2 to 3.1 cm per cm of percolating rainfall respectively. However, when rainfall was more intermittent and of low intensity (7 Feb. - 5 Mar. 1973) rates slowed to 0.6 cm per cm of total rainfall and 1.55 cm per cm of percolating rainfall due to greater adsorption of incident rainfall in surface layers of the soil profile.

All sampling on the Tindall soil prior to the cessation of rainfall was conducted to a depth of 105 cm and within this depth rates did not seem to be related to the depth interval through which nitrate was leached. If rainfall had continued longer through the grain filling period, rates may have slowed
with increasing depth of displacement due to nitrate absorption as demonstrated by Black and Waring (1976a). Profile trends in attributes such as pH, organic carbon and kaolinite content lend support for the increasing influence of nitrate adsorption (Black and Waring 1976b) at depths below 100 cm in both Tindall and Blain soils, but not in the case of the Emu.

Intermittent low intensity rain fell on the Blain site during the first 12 days following fertilizer application, resulting in very rapid leaching of nitrate through the sandy A horizon of this soil. The lower limit of this surface horizon was determined as 45 cm. Apparent leaching rates for this period were of the order of 3.4 cm per cm of total rainfall and 5.0 cm per cm of percolating rainfall.

During the time intervals 18 January to 9 February 1973 and 10 February to 9 May 1973, rainfall was of a high intensity, however leaching rates through the clay B horizon of the Blain soil were much slower due to the greater proportion of fine pore sizes when compared to the A horizon (Day, unpub. data). For the above periods, apparent leaching rates varied from 1.8 to 1.6 cm per cm of total rainfall and 2.4 to 2.8 cm per cm of percolating rainfall respectively. In terms of total rainfall, there appears to be a gradual reduction in the rate of nitrate displacement with increasing depth of accumulation but this trend is not supported by rates expressed in terms of percolating rainfall.

Due to the extreme length of the sampling intervals shown in Table 2 for the Emu site; it is difficult to relate apparent nitrate leaching rates to particular rainfall intensities and duration, however, each sampling interval included periods of high intensity rainfall. Apparent leaching rates for the loamy
Emu soil were of the order of 1 cm per cm of total rainfall and varied from 1.85 to 2.88 cm per cm of percolating rainfall. Such rates are of a similar order to those found for the Tindall soil during periods of high intensity rainfall.

Apparent leaching rates of native nitrate appeared to be of the same order as those for applied nitrate in all three soils, although a direct comparison of leaching through a particular depth interval for any one time period is not possible. The initial displacement of native nitrate occurred from more than one depth interval and commenced prior to the addition of nitrogen fertilizer.

Recovery of nitrogen by the crop

In this study the interpretive value of plant data was limited due to some grain attack by birds prior to harvest. Plant nitrogen values indicate that 13 and 20 per cent of applied nitrogen was taken up by grain sorghum crops on the Emu and Tindall soils respectively and virtually no applied nitrogen was recovered by the crop on the Blain. In fact the presence of a crop made little difference to the rates and extent of nitrate displacement as found for other examples of sandy and loamy red earths of this region, in the bare fallow condition (Wetselaar, 1962a).

Recent studies on the root development of similar hybrid grain sorghums grown on a Tindall red earth of this region emphasize the shallow rooting habit of this crop (Myers, personal communication). This work has shown that about 80 per cent of the sorghum root length is confined to the 0 to 40 cm depth and 90 per cent to the 0 to 80 cm depth at crop maturity. Approximately one-half of this total root development had occurred by floral initiation and three-quarters by anthesis.
On the Tindall soil used in this study, applied nitrogen was thought to be available for plant uptake prior to the anthesis growth stage, with the bulk of applied nitrate above a depth of 60 cm. However, during early grain filling, applied nitrate was leached from the upper 45 cm of the Tindall soil and this must represent a major loss of nitrogen from the root zone.

No previous root studies have been conducted on soils of the Blain family but more rapid root proliferation is expected. With the removal of applied nitrate below a depth of 45 cm at floral initiation, and below 90 cm at anthesis, nitrate leaching represents a major avenue of nitrogen loss to grain sorghum crops grown on the Blain. This is confirmed by the failure to recover applied nitrogen in either plant tops at anthesis or grain samples at crop maturity. Crop nitrogen uptake from the Emu soil was also considerably reduced due to the displacement of applied nitrate from the 0 to 60 cm depth by floral initiation.

PRACTICAL IMPLICATIONS

Nitrate distribution curves clearly demonstrate displacement of nitrate to much greater depths and at faster rates in the Blain soil when compared to the Tindall under grain sorghum crops. This is due mainly to the greater proportion of rainfall entering the sandier Blain and differences in saturated hydraulic conductivity between soils. Leaching rates were of the same order between Tindall and Emu soils, but the much higher rainfall on the Emu site caused deeper displacement than in the Tindall.

Blain soils present a serious problem in the supply of nitrogen to crops such as grain sorghum since both naturally occurring and applied nitrate are leached rapidly through the sandy A horizon during critical early growth stages.
Since fertilizer application in the ammonium nitrogen form provides only a temporary solution, and leaching in that form may also occur in this soil horizon, split applications of nitrogen would seem to be essential if Blain soils are to be productive. Split application of nitrogen may also improve the efficiency of nitrogen fertilizer usage in the finer textured Tindall and Emu soils.

These results emphasize the importance of a deep rooting fodder crop such as Bullrush millet to recover nitrate accumulated at depth below grain sorghum crops in this tropical monsoonal climate.

ACKNOWLEDGEMENTS

The technical assistance of Messrs. P.J. McLeod and I.R. Hall is gratefully acknowledged. I thank Mr. H.A. Nix of C.S.I.R.O. Division of Land Use Research for assistance in the processing of soil moisture data, and Mr. R.L. Henderson for the preparation of illustrations.
APPENDIX I

ESTIMATION OF RAINFALL PERCOLATING THE SOIL PROFILE

The model Cropeval developed for summer grown, dryland grain sorghum was used to simulate the soil water balance. Within this model a potential evapotranspiration function similar to that described by Slatyer (1960) was used. The ratio of potential evapotranspiration to evaporation from an open water surface \( \frac{E_t}{E_o} \) was assumed to vary as the crop passes through successive developmental phases.

In the accompanying actual evapotranspiration function, the dependent variable was taken as the ratio of actual to potential evapotranspiration \( \frac{E_a}{E_t} \), and as the independent variable the relative available water \( R \). The levels assigned to the steps in this function ranged from \( \frac{E_a}{E_t} = 1.0 \) at \( R = 1.0 \) to \( \frac{E_a}{E_t} = 0.4 \) at \( R = 0 \).

In this model, the soil profile is treated as an unstratified reservoir with soil moisture equally available to plant roots at all depths. Since greatest variation in measured moisture content during cropping occurred in the upper 60 cm of all sampled profiles, a maximum sampling depth of one metre was chosen. For Tindall and Emu soils, maximum soil storage values of 82 and 132 mm were adopted, representing water retained between \(-1/3\) and \(-15\) bar to a depth of one metre. A storage value of 109 mm for water retained between field capacity and \(-15\) bar was used for the duplex Blain profile due to a lack of agreement between \(-1/3\) bar and field capacity measurements.
Input data were daily rainfall on site and district pan evaporation, accumulated as weekly totals. At the commencement of the wet season the soil storage value was assumed zero for the model, hence antecedent subsoil moisture from the previous year was not accounted for. Throughout the wet season, available soil moisture and actual evapotranspiration were computed on a weekly basis.

The model tended to overestimate the available water status of the two loamy red earths Tindall and Emu, since run-off losses were not accounted for in the recharge of soil water. This difference between measured and estimated available water was assumed to represent run-off and was calculated as a percentage of incident rainfall between sampling intervals on each site over two wet seasons, 1971/72 and 1972/73. Run-off losses were highly variable but were thought to account for 30 and 20 per cent of incident rainfall on the Tindall and Emu soils respectively. Examples of such comparisons for Tindall and Emu soils during the 1971/72 wet season are given in Figures 4 and 5 respectively. Percolating rainfall on the Tindall and Emu sites was then estimated by subtracting actual evapotranspiration and the run-off component from the incident rainfall for each sampling interval.

Run-off from the Blain site was thought to be negligible since the site was without slope and surface infiltration rates have been shown in the previous paper to be very high compared to the other two soils. Consequently measured available soil moisture values were found to be equal to or slightly greater than computed values. Examples of such results are given in Figure 6 for the 1971/72 wet season. Rainfall percolating the Blain soil was then estimated simply by subtracting actual evapotranspiration from incident rainfall for each sampling interval.
Figure 4. Comparison of estimated and measured soil water changes in a Tindall red earth under sorghum (Katherine, N.T.).
Figure 5. Comparison of estimated and measured soil water changes in an Emu red earth under sorghum (Tipperary Station, N.T.).
Figure 6. Comparison of estimated and measured soil water changes in a Blain red earth under sorghum (Tipperary Station, N.T.).
REFERENCES


3. Grain sorghum fertilizer requirements under dryland conditions

K.J. Day
SUMMARY

Grain sorghum was grown on three red earths of the Tindall, Blain and Emu soil families. Various rates of nitrogen, phosphorus, potassium and sulphur fertilizers were applied to assess the productivity of these soils under dryland conditions, over two to three growing seasons.

No significant response was found to the addition of potassium or sulphur to any of the three soils. Sorghum grown on the recently cleared loamy Tindall red earth exhibited highly significant responses to both nitrogen and phosphorus addition and a significant nitrogen-phosphorus interaction. However, the magnitude of both nitrogen and phosphorus responses varied markedly in subsequent seasons due to the influence of native mineral nitrogen supply, leaching of nitrate nitrogen and soil water status in relation to stage of crop growth.

Similar responses to both nitrogen and phosphorus addition were found for the sandy Blain red earth, however responses were so dependent upon seasonal variation in rainfall distribution as to raise doubt on the suitability of this soil for continuous cropping purposes.

Yield results from the loamy Emu red earth did not demonstrate significant responses to the addition of either nitrogen or phosphorus. However there is evidence to show that the magnitude of the response to applied nitrogen would have been reduced due to early leaching and the presence of large amounts of native mineral nitrogen at sowing.
Results of this study have demonstrated the need to monitor a wide range of soil and climatic variables to accurately assess soil productivity using this field trial approach. Without a knowledge of the effects of such variables, it is difficult to reliably predict fertilizer requirements in future seasons.
INTRODUCTION

To achieve the overall objective of the National Soil Fertility Project, the productivity of the three red earth soils was assessed by conducting a factorial designed fertilizer experiment over a limited number of growing seasons. Grain sorghum (Sorghum bicolor Dekalb E57) grown under dryland conditions was utilised as the test plant for this study.

Considerable grain sorghum nutrition work on red earths has been conducted in the tropical monsoonal region of the Northern Territory, which receives an annual rainfall ranging from 704 to 1298 mm. Since all work has concerned dryland grain sorghum, the fundamental problem encountered has been the difficulty which variation in seasonal rainfall distribution imposes on obtaining satisfactory grain yields for comparative purposes (Arndt, Phillips and Norman, 1963; R. Wetselaar, personal communication; Doughton, 1971).

It is widely known that red earths of the Daly Basin are deficient in phosphorus (P) and nitrogen (N). Responses in terms of sorghum grain yield to the application of P have been found on a range of recently cleared loamy red earths similar to the Tindall and Emu soils used in this study. Optimum application rates varied from 24 to 48 kg P per ha (Arndt and Phillips, 1961; Doughton, 1971, 1974). A very marked N-P interaction was observed in the same experiments. However, no response to the application of P could be found with sorghum grown on a very sandy red earth of the Blain family, located in the same region (Arndt and Phillips, 1961). This result was unexpected considering the low P status of this soil. Crop failure and generally poor yields on other Blain sites have not enabled clarification of this result (Arndt, Phillips and Norman, 1963 and C. Robbins personal communication).
With an adequate supply of P, grain yield responses to the application of N have been found on recently cleared loamy red earths, with optimum application rates ranging from 46 to 56 kg N per ha (Arndt and Phillips, 1961; Doughton, 1971, 1974). Unfortunately the literature does not indicate the magnitude of grain yield responses to the application of N to sorghum crops grown on sandy red earths of the Blain family.

Interpretation of crop yield responses to applied N on such widely differing red earths must be carefully made because of the contribution from native mineral N. As reported in a preceding paper of this study and by Wetselaar (1967), the rate of mineralisation and the proportion of organic nitrogen mineralised with the onset of wet season rains depend largely on soil type and land history. It is thought that between 60 and 85 kg N per ha may be mineralised from organic nitrogen sources in the surface 30 cm depth of red earth soils, and a crop such as grain sorghum may recover between 20 and 60 per cent of this amount (R. Wetselaar personal communication). Crop recovery of native mineral N will depend greatly on the effect of soil moisture and temperature on mineralisation, and the incidence of leaching early in the growing season.

Little field work has been conducted to evaluate grain sorghum responses to plant nutrients other than N and P, with the exception of work by Arndt and Phillips (1961). On a loamy Tippera red earth similar to the Tindall used in this study, Arndt and Phillips found no response in sorghum yield to the application of potassium (K), sulphur (S) and a wide range of minor elements. Considerable work is required before this finding can be extrapolated to a wide range of red earths, in particular to those soils with coarser textures.
In this paper, nutrient responses are reported for three soils as determined by a series of field experiments, and results are related to factors such as nitrogen leaching and moisture stress at various crop growth stages. Such factors are highly dependent upon seasonal conditions. It is hoped to demonstrate the importance of monitoring certain components of the nitrogen cycle in interpreting yield results and to highlight the predominant influence of various climatic and soil hydrological properties in dryland crop management on red earths.

MATERIALS AND METHODS

In the preceding two papers of this series, considerable information has been detailed on the location of sites, and differences in various soil characteristics which may affect plant growth. Crop establishment methods, plot size and sampling procedures adopted for the measurement of soil moisture content, mineral nitrogen, and plant analyses have also been described in detail.

At each site a completely randomised half replicate of the factorial design 4N x 4P x 2K x 3S was laid out. Different randomisations were utilised for each successive season and at each site. Levels of applied nutrients were the same at all sites. Nutrient levels and the respective fertilizer carriers are presented in Table 1.

<table>
<thead>
<tr>
<th>Element and carrier</th>
<th>elemental levels (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N Nitram</td>
<td>0  22  56  112</td>
</tr>
<tr>
<td>P Triple super</td>
<td>0  11  28  56</td>
</tr>
<tr>
<td>K Muriate of potash</td>
<td>0  67</td>
</tr>
<tr>
<td>S Gypsum</td>
<td>0  17  45</td>
</tr>
</tbody>
</table>
All fertilizer was drilled with a tined implement to a depth of 7 cm, with rows 18 cm apart, immediately prior to sowing. To allow for variable establishment conditions between sites, a sowing rate of 9 kg seed per ha was used on all sites to provide a plant population density of between 15 and 20 plants per m². Plant rows were spaced 36 cm apart.

The Tindall site was investigated over three wet seasons, from 1971 to 1973, with a mean population density of 19 plants per m². Field trials on the Blain and Emu sites commenced a year later and were conducted over 2 wet seasons, 1972 and 1973. The mean population on the Blain was 18 plants per m², but was considerably less on the Emu site at 15 plants per m² due to a soil surface crusting problem and seedling loss through bird attack.

Grain yields at maturity or when excessively damaged by pests, the dry weight of plant tops at anthesis were statistically analysed by a regression technique which evaluated linear and quadratic main effects and two-factor interactions.

Throughout this paper, certain of the physiological growth stages as defined by Vanderlip and Reeves (1972) for Sorghum bicolor have been used, and are described as follows: emergence, when the coleoptile is visible at the soil surface (three to ten days after sowing); floral initiation, approximately one third of the time required for physiological maturity (21 to 30 days after emergence); boot, when the head is nearly full length and enclosed in a flat leaf sheath; anthesis, when approximately half the plants are at some stage of bloom or pollen shed (approximately 8 weeks after emergence); soft dough, when approximately one half of the grain dry matter has accumulated; maturity, when the maximum dry weight of the total plant has been reached.
Using the soil moisture model described in the preceding paper, the ratio of estimated actual evapotranspiration (Ea) to potential evapotranspiration (Et) was calculated on a weekly basis. For periods when this ratio was less than unity, the crop was assumed to be under moisture stress. The frequency of moisture stress may be related to the stage of crop growth. Nix and Fitzpatrick (1969) found that for dryland grain sorghum, the incidence of moisture stress after boot through anthesis to early grain filling was highly correlated with grain yield, and explained much of the intra-seasonal and year to year differences in varietal yield. This growth stage was referred to as the critical ontogenetic period.

RESULTS

Tindall

Grain yields were obtained over three seasons (1971-1973) from the loamy Tindall red earth, however considerable grain was lost through attack by birds during the final season. Statistical analysis of the results revealed coefficients of variation of 18, 16 and 38 per cent for the 1971, 1972 and 1973 seasons respectively. In this comparison, the results of the 1973 season are regarded only as a guide to probable grain yield response trends.

At the five per cent probability level, a significant linear response was found to the addition of P in all three seasons, and to the addition of N in the first two seasons only. A significant N x P interaction was detected in the first season alone. No response or interaction was detected to the addition of K or S. The magnitude of the various grain yield responses is indicated in Figure 1 for the three growing seasons on this soil.
Closer alignment of the curves on each graph with consecutive seasons illustrates the reduced response to the addition of N, and a weaker N x P interaction. These responses may be explained by variable conditions for nitrogen leaching and different amounts of native mineral nitrogen available in the surface soil between seasons.

Applied and native nitrate-N remained in the upper 60 cm of the soil profile throughout the 1971 growing season, but was leached below this depth by mid-grain filling in 1972, and soon after anthesis in the 1973 season. Hence nitrate-N was less accessible to plant roots with each successive season.

Native mineral nitrogen formed at the onset of wet season rains was found to increase with each fallow year on the Tindall soil. As measured close to sowing, the amount of native mineral N was found to be 54, 82 and 119 kg N per ha to a depth of 30 cm for the 1971, 1972 and 1973 seasons respectively. It is thought that such increases in the supply of mineral N would substantially reduce the magnitude of any grain yield response to added N.

During the initial growing season (Figure 1a) the optimum fertilizer application rates approximate to 45 kg P per ha, together with 56 kg N per ha to achieve a grain yield of 2500 kg per ha. Examination of \( \frac{Ea}{Et} \) values for this 1971 season indicated adequate crop water supply for almost the entire growing season with the exception of a short moisture stress period at boot to early ear emergence. Total rainfall for this wet season was above average and evenly distributed, particularly during the critical anthesis to early grain filling growth stages.

Results from the second growing season (Figure 1b) indicate a greater magnitude of response to added P at all levels of N, with an optimum P response greater than the maximum application
Figure 1. Sorghum grain yield response trends to the addition of N and P on a
Tindall red earth. N applied: 0kg/ha x --- x; 22kg/ha o---o;
56kg/ha o---o; 112kg/ha o---o
of 56 kg P per ha. The increased response is also reflected in much higher recovery of added P in harvested grain. This particular crop experienced moisture stress early in the growing season at the floral initiation growth stage, and later throughout the grain filling period. Grain yield did not seem to be depressed by these stress periods, with yields in excess of 2,500 kg per ha at high rates of N and P. Total rainfall for this wet season was above average but not as evenly distributed as for the previous year.

For the final growing season (Figure 1c), results indicate generally depressed yield responses, with grain yields between 2,000 and 2,500 kg per ha at high rates of N and P. The reliability of this assessment was lowered due to grain loss through bird attack. The shape of the response curves at high N levels again indicates that the maximum P application rate of 56 kg per ha was below the optimum P requirement. A considerable difference in grain yield occurred between each applied N level at the maximum P application even though the N response was non-significant at the five per cent probability level. Crop moisture stress during this 1973 season occurred during early grain filling, and severe stress during the final five weeks of growth. Such stress periods may have influenced the lowering of grain yields. Total rainfall for this wet season was below average, and distributed chiefly in four groups of consecutive wet days.

Blain

Insect and bird damage to sorghum grown on the sandy Blain red earth have limited the interpretation of results from this site.

As a result of severe sorghum midge (Contarinia sorghicola) attack during the 1972 growing season, the dry weight of plant
tops at the anthesis growth stage were substituted for grain yields. In the following 1973 season, grain yields were obtained, however some grain particularly from high nitrogen treatment plots was lost through attack by birds.

A coefficient of variation of 30 per cent resulted from statistical analysis of each set of data, hence interpretation is attempted only as a guide to probable plant responses. In both seasons a significant linear response to the addition of N and P was found at the five per cent probability level, with much stronger responses shown in the dry weight data of the 1972 season. A significant N x P interaction was detected only in the first season.

Figure 2. Sorghum dry weight yield responses to the addition of N and P on a Blain red earth. N applied: 0kg/ha x –––x; 22kg/ha • ––●; 56kg/ha ○ ––○; 112kg/ha ♦ ––♦.
Dry weight yield responses for the 1972 growing season (Figure 2) demonstrate an increased plant requirement for P at each level of N, with optimum requirements greater than the maximum N and P levels used in this design. During this season, applied nitrate - N remained available for plant uptake in the upper 60 cm of the soil profile until the stem elongation to early boot stage of growth, hence the dry weight growth responses to the application of N.

Grain yields were severely depressed in the 1973 season due to the lack of nitrate - N early in the growing season and the occurrence of crop moisture stress at the critical boot through anthesis to soft dough stages. The maximum grain yield achieved was 738 kg per ha. Since nitrate - N was leached below a depth of 60 cm soon after the floral initiation growth stage of this season, plant N uptake later in the season was limited to small amounts of native mineral N and consequently yield responses to the addition of both N and P were much weaker.

Crop moisture stress occurred during grain filling in both seasons. Soil moisture appeared to be extracted chiefly from the upper 60 cm of the soil profile during stress periods, leaving considerable reserves of water below this depth. At crop maturity, approximately 89 and 50 per cent of the available moisture storage capacity to a depth of one metre remained in the soil at the conclusion of the 1972 and 1973 growing seasons respectively.

As for the Blain site, plant dry weight data at anthesis were utilised in lieu of grain yields due to severe attack by sorghum midge (Contarinia sorghicola) during the 1972 season. Analysis of these data show that responses to all applied nutrients were
very weak and not significant at the five per cent probability level. It is known that these dry weight data are far from ideal, however several findings give support to the lack of response to applied N and P on this red earth. The presence of 56 kg of native mineral N per ha - 30 cm soon after sowing and almost complete leaching of applied nitrate - N below a depth of 60 cm after the anthesis growth stage would reduce the effect of added N. At lower N levels, plant growth response to applied P may also be depressed.

Grain yields were obtained in the following 1973 season but again responses to all applied nutrients were weak and not significant at the five per cent probability level. These yield data were found to have a coefficient of variation of 21 per cent, caused mainly by grain loss from some plots through attack by birds. It is presumed that much of the N utilised by the crop was obtained from native mineral N, with 105 kg of native mineral N per ha - 30 cm present 11 days after sowing, and applied nitrate - N was leached below a depth of 60 cm approximately two weeks after floral initiation. Under such conditions the response to applied N would be considerably reduced.

Nevertheless grain yields in this season were generally quite satisfactory with many plots yielding the equivalent of 2 000 to 3 000 kg per ha. This suggests that if more reliable yield data had been obtained, the effect of applied P may have been quite significant despite the incidence of crop water stress during grain filling.

DISCUSSION

On the application of N and P fertilizers to the loamy Tindall red earth, grain yield responses during the first growing season were found to be of similar order to those reported in
the literature for other recently cleared loamy red earths of the Daly Basin. However, the magnitude of such responses to both N and P on adjacent land in subsequent seasons was strongly dependent upon the length of fallow, total rainfall and rainfall distribution.

The response to added N in each season on the Tindall soil was strongly influenced by the build up of native mineral N reserves with each year of native grass fallow, and leaching of applied nitrate - N in relation to critical sorghum growth stages. The significance of any N x P interaction also depended upon the removal of nitrate - N from the root zone.

The potential grain yield in any one particular season on the Tindall soil was also governed largely by rainfall distribution due to its influence on the frequency and duration of crop moisture stress periods, and the rate and extent of nitrate - N leaching.

This investigation on the Blain and Emu red earths has not yielded a satisfactory quantitative assessment of the various nutrient responses, and a larger number of seasons need to be monitored to do so, free of insect pests and predators.

On the sandy Blain soil, a study of nitrate - N distribution with soil depth has demonstrated a very marked difference in the availability of applied nitrate - N between seasons, depending on rainfall distribution in relation to stage of crop growth.

This seasonal variation in N availability on the Blain is greater than that encountered for the loamy Tindall and Emu soils, and may render N fertilizer virtually non-effective if it is applied to the Blain at sowing and strong leaching conditions occur soon after.
The physical characteristics of the Blain soil in a level situation permit very rapid rates of infiltration and hydraulic conductivity with consequent storage of available water below the A horizon. This study over only two growing seasons indicates that a pasture species might be better adapted to utilise the longer growing season afforded by subsoil water storage, than a crop with high nutrient requirements such as grain sorghum. In gently sloping situations the erosive nature of this soil also favours its suitability for pasture production.

The lack of or the failure to detect a significant response to the addition of N and P fertilizers to the loamy Emu red earth is unexpected. The inherent nutrient status of the Emu soil is similar to that of the Tindall as discussed in the first paper of this series, with the exception of greater reserves of organic carbon and nitrogen in the former soil. Unreliability in yield data obtained from this site is thought to be responsible for this apparently anomalous finding.

To provide a more accurate prediction of the fertilizer requirements of grain sorghum grown on red earths of the Daly Basin, a much larger number of growing seasons need to be monitored, incorporating both continuous crop-fallow sequences and crop-legume rotations over a wide range of red earths.

Due to differences in the inherent soil physical characteristics of the three red earths involved in this study, certain factors have been found to have an over-riding influence on grain yield potential, and require emphasis during future studies. These factors are soil moisture availability to the crop under high run-off conditions, fluctuations in the organic N fraction which is readily mineralised at the commencement of the wet season and the rate and extent of nitrate leaching.
ACKNOWLEDGEMENTS

I am grateful to the staff of the Katherine Experimental Farm and to the management of Tipperary Station for assistance during the course of the work. Messrs. P.J. McLeod and I.R. Hall gave capable technical assistance in the field. I thank Dr. J.D. Colwell of C.S.I.R.O. Division of Soils for providing randomised designs and for the statistical analysis of data, and Mr. R.L. Henderson for the preparation of illustrations.
REFERENCES


