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Long-term Trends in Fertility of Soils under Continuous Cultivation and Cereal Cropping in Southern Queensland. I Overall Changes in Soil Properties and Trends in Winter Cereal Yields

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Abstract

Changes in fertility of some southern Queensland soils resulting from extended periods of cultivation are presented, together with trends in yields of winter cereals on these soils. Six major soils of the cereal-belt, cropped for maximum periods of 20–70 years were examined. These were: Black earths, Waco soil; grey, brown and red clays (brigalow), Langlands-Logie soil; grey, brown and red clays (poplar box), Cecilvale soil; grey, brown and red clays (belah), Billa Billa soil; grey, brown and red clays (coolibah), Thallon soil; red earths, Riverview soil. Organic matter and its constituents, especially total organic C, organic C in the light fraction, total N and mineralizable N, were affected most by cultivation, showing decreases of 19–67% overall. Other soil properties probably associated with organic matter, including bulk density and DTPA (diethylenetriaminepentaacetic acid) extractable manganese, were also significantly affected by cultivation in all soils.

Soil properties affected least by cultivation were concentrations of inorganic phosphorus, total and exchangeable potassium, calcium carbonate, and dithionite extractable iron and aluminium. Most other soil properties studied (organic P, total sulfur, pH, exchangeable magnesium and sodium, exchangeable sodium percentage, and oxalate-extractable iron and aluminium) were affected by cultivation in at least four soils.

Four factors accounted for 70% of the total variation among the 45 soil properties considered. They appeared to represent organic matter, clay colloids, iron and aluminium oxides, and soluble salts. Dry matter yield and/or N uptake of winter cereal crops (wheat and barley) measured in 1983 showed significant decreasing trends with period of cultivation in all soils.

Introduction

Cultivation and cropping of soil affect its chemical, physical, and biological characteristics. Cultivation of a soil previously supporting native vegetation or pasture generally leads to reduced organic matter, organic carbon and nitrogen (Clarke and Marshall 1947; Haas *et al.* 1957), deterioration in soil structure (Baver 1968), and lower biological activity (Khan 1970). This is primarily due to changes in temperature, moisture fluxes and aeration, to exposure of new soil surfaces resulting from aggregate disruption, to reduced addition of organic materials, and frequently to increased soil erosion.

Long-term effects of cultivation and cropping on soil organic matter have been studied in temperate and Mediterranean environments (Cooke 1967; Russell 1981; Odell *et al.* 1984), but less so in subtropical and tropical regions. Jenny and Raychaudhuri (1960) observed 60–70% loss of organic matter from long-cultivated Indian soils. Martin and Cox (1956) found that, in the first 25 years of cultivation, a heavy clay soil (Vertisol) in Queensland lost nitrogen at the rate of 0·8% per year of the amount in the top 0·15 m. Russell (1981) observed higher N losses (about

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5% per year) from an initially virgin grey brown clay soil (Vertisol) cropped to sorghum continuously for 10 years; sorghum yields also decreased. Other constituents of organic matter such as phosphorus and sulfur also decline with cultivation. Williams and Lipsett (1961) found that approximately 17% of organic P and 30% of organic S were mineralized when soils were cultivated for wheat for 50–60 years.

Exchangeable calcium, magnesium and potassium, and cation exchange capacity of soils are also reduced by long periods of cultivation (Williams and Lipsett 1961). These effects may result partly from loss in organic matter, but differences in water fluxes (downward and upward movement, evaporation and transpiration, infiltration and runoff) due to changes in vegetation upon cultivation may also affect exchangeable cations and salinization in soil.

In temperate soils, deterioration in soil structure with cultivation results in lower aggregate stability (Marshall 1962), higher bulk density (Stephens *et al.* 1945), and often increased erosion (Stephens *et al.* 1945). The effects of long-term cultivation on physical properties in subtropical soils are less known.

In Queensland, wheat and barley are grown in winter, and sorghum and sunflower in summer, usually following 6–12 months' fallow, in continuous sequences. Large areas have relatively recently been cleared of native vegetation for cropping, and clearing is continuing. The study reported here and in subsequent papers was aimed at determining how these soils have reacted to such intensive use in a subtropical environment. Understanding of soil fertility trends should indicate more clearly the need for changes in cropping and cultural practices and for research related thereto. Six important soils were examined for changes in chemical, physical and biochemical properties over extended periods of cultivation, and the effect of cropping history on current crop yield was assessed. This paper reports overall changes in soil properties of the top layer (0–0·1 m) resulting from cultivation and cropping, together with trends in yields of winter cereals in relation to the period of cultivation and cropping.

Materials and Methods

Location of the study area is shown in Fig. 1. Mean annual rainfall (83–101 year period) for Dalby, Chinchilla, Goondiwindi, Surat and Thallon are 670, 630, 610, 580 and 480 mm respectively. Approximately 35% of annual rainfall is received in winter months (April to September inclusive). The corresponding mean annual temperatures are 18·5, 19·4, 19·9, 20·3 and 20·5°C, respectively. The region and its agricultural potential have been described by Weston *et al.* (1975).

The Soils

The soils studied were located as shown in Fig. 1. A general description of the six soil series and the dominant natural vegetation growing on each is given in Table 1. The Waco and Cecilvale clay soils are described by Beckmann and Thompson (1960) and Reeve *et al.* (1960), and Langlands and Logie soils are described by Dawson (1972). The profile descriptions of Billa Billa, Thallon and Riverview are given in Appendix 1 (B. Slater, personal communication), and general descriptions of these soils are also given by Isbell (1957) and Galloway *et al.* (1974). The soils are described briefly below:

Waco. Very deep, black to greyish brown self-mulching, weakly gilgaied, cracking clays with an alkaline reaction trend at depth. The parent material is clay alluvium derived from basalt. Slope is less than 0·5%.

Langlands-Logie. Very deep, ranging from dark greyish brown to dark brown cracking clays which are alkaline at or near the surface and acid at depth. There is a fairly strong gilgai microrelief (shelf to depression, 0·2–0·4 m). Parent material is alluvial clayey sediments formed from light grey shales, silt-stones, and fine to medium sandstones. Slope is less than 1%.

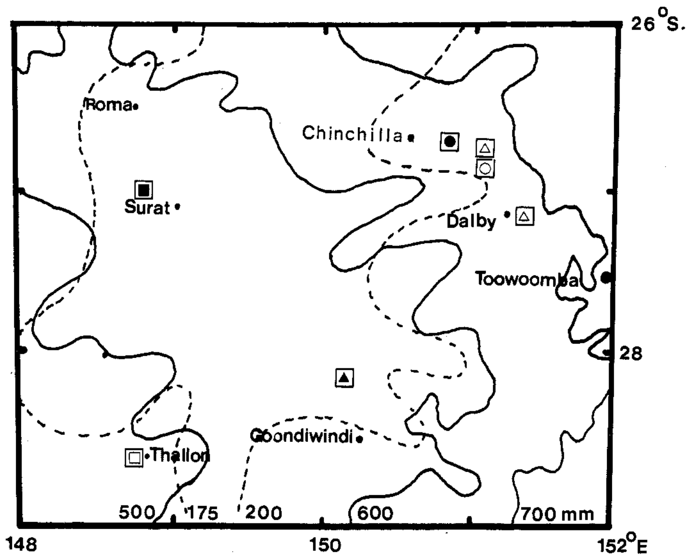

Fig. 1. Map of southern Queensland showing isohyets of mean annual rainfall (——) and winter rainfall (– – –) (Weston 1975). The study areas are located on Waco (○), Langlands-Logie (●), Cecilvale (△), Billa Billa (▲), Thallon (□) and Riverview (■) soils.

Table 1. The soils and natural vegetation

Soil series	Classification			Soil texture	Clay minerals[D]	Dominant natural vegetation
	Great Soil Group[A]	Factual Key[B]	Soil Taxonomy[C]			
Waco	Black earth	Ug 5.16	Typic Pellusterts	Clayey	S,K,Q,I[E]	*Dichanthium sericeum*
Langlands-Logie	Grey, brown and red clays	Ug 5.24	Typic Chromusterts	Clayey	Q,R.I.,K[E]	*Acacia harpophylla*, *Casuarina cristata*
Cecilvale	Grey, brown and red clays	Ug 5.41	Typic Chromusterts	Clayey	R.I.,Q,K,I[E]	*Eucalyptus populnea*, *Dichanthium sericeum*
Billa Billa[G]	Grey, brown and red clays	Ug 5.25	Typic Chromusterts	Loamy clay	Q,R.I.,K,I[F]	*Casuarina cristata*, *Eremophila mitchellii*, *Geijera parviflora*
Thallon[H]	Grey, brown and red clays	Ug 5.24	Typic Chromusterts	Clayey	K,I,S,Q[F]	*Eucalyptus microtheca*, *Astrebla lappacea*, *Acacia pendula*
Riverview	Red earth	Gn 2.11 Gn 2.12	Rhodic Paleustalfs	Sandy loam	K,Q,I,H[F]	*Eucalyptus melanophloia*, *Ermophila mitchellii*, *Eucalyptus populnea*

[A] After Stace *et al.* (1971). [B] After Northcote (1971). [C] USDA Soil Survey (1975). [D] Minerals in order of decreasing abundance: S, smectite; K, kaolinite; I, illite; Q, quartz; R.I., randomly interstratified; H, Hematite. [E] J. O. Skjemstad (unpublished data). [F] Predicted from Gunn (1974). [G] Also Medpark (Ug 5.24) and TeApiti (Ug 5.33). [H] Also Birra Birra (Ug 5.29).

Cecilvale. Deep, greyish brown to black, weakly gilgaied, cracking clays which are alkaline at depth. Parent material is clay alluvium derived from basalt and sandstone. Slope is less than 1%.

Billa Billa. Deep, greyish yellow brown, light medium clays which are alkaline at or near the surface and acid at depth. There is a weak gilgai microrelief (<0·2 m). Soils are derived from weathered calcareous sediments and occur on a gently undulating (slope 1%) landscape.

Thallon. Deep, brownish black, medium clays with an alkaline reaction trend at depth (0·7–1 m). There is some evidence of incipient gilgai (0·1 m deep). Parent material is Quaternary argillaceous alluvium. Slope is less than 1%.

Riverview. Deep, dark reddish brown, sandy clay loams, neutral to acid in reaction. They occur on a very gently undulating landscape (slope 1%). Parent material is weathered ferruginized sediments.

Crop Management Practices

The period of cultivation, number of winter and/or summer crops per year, rate of fertilizer applications, stubble retention and number of cultivation operations per year were tabulated from farmers' records (Table 2). Winter crops were wheat (90%), barley (9%) and oats (1%) and summer crops were sorghum (90%) and sunflower (8%). In recent years cultivation operation during the fallow period have consisted typically of one or two each with a chisel plough, sweep plough and scarifier, and occasionally a disc plough. In the earlier years (before approximately 1960) greater use was made of disc implements and in some instances mouldboard ploughs were employed for primary tillage. The number of cultivation operations in the study area appears to follow mean annual rainfall, presumably reflecting the need to control weeds. The use of fertilizer (mainly anhydrous ammonia, urea and monoammonium phosphate) is restricted to the Dalby (Waco and Cecilvale) and Chinchilla (Langlands–Logie) areas.

Soil Sampling

Soil samples were collected, generally during April–July, from farmers' fields that had been under cultivation for 0·5–70 years, and from an adjacent area that had never been cultivated. The samples were taken at 0–0·1, 0·1–0·2, 0·2–0·3, 0·3–0·6, 0·6–0·9 and 0·9–1·2 m depths by a hydraulically operated sampler with a 46 mm diameter cutting edge.

Representative soil samples were obtained at each site by sampling 0·1 ha areas on a 5 m by 8 m grid. This grid pattern was followed even in gilgai areas because separate sampling of shelf and depression areas was not feasible due to partial levelling of the gilgais during cultivation. From a preliminary investigation it was found that representative samples were obtained in this manner. Five samples, each from 0–0·1, 0·1–0·2 and 0·2–0·3 m depths, and two samples, each from 0·3–0·6, 0·6–0·9 and 0·9–1·2 m, were mixed to obtain composite samples at respective depths. Five composite samples were obtained from each depth. The soil samples were sealed in plastic bags in the field and stored at 4°C until further processing.

Soil moisture content was determined by drying a subsample at 105°C for 24–48 h. The field bulk density was calculated from the oven-dried soil weight contained in the field volume of the soil sample. The remainder of the soil sample was dried at 25°C in a forced-draught oven, ground to pass a 2 mm sieve (0·25 mm sieve for organic C and total N determination) and stored in sealed plastic containers.

Plant Sampling

Plant samples of winter crops were collected in 1983 from the areas where soil samples had been obtained, by harvesting 10 quadrats (0·5 m^2 each) at maturity. Dry matter yields were obtained by drying the plant samples at 80°C for 24–48 hr. Grain and straw were then separated, weighed, ground to pass a 1 mm sieve and stored in sealed plastic containers.

Analytical Techniques

Total soil organic C and that in the light fraction (density $<2\cdot0$ Mg m^{-3}) were determined by the Walkley and Black method adapted for spectrophotometric determination (Sims and Haby 1971). The light fraction was obtained by a slightly modified procedure of Richter *et al.* (1975), and the sample was dried at 80°C for at least 6 h. Total N in soil was determined by the Kjeldahl method (Bremner 1965), and that in the plant material by the procedure described by Jackson (1958). Total P, sulfur, potassium and zinc in soil were determined by X-ray fluorescence spectrometry. Organic P was determined by the ignition procedure of Saunders and Williams (1955). Calcium carbonate was estimated by loss in soil weight upon addition of HCl containing $FeCl_2$ (Bauer *et al.* 1971). Oxalate and dithionite extractable aluminium and iron in soil were determined according to Schwertmann (1964) and Asami and Kumada (1960), respectively.

Soil pH and electrical conductivity measurements were made in 1:5, soil:H_2O, suspension. Total cation exchange capacity and exchangeable cations were estimated by the displacement method using alcoholic NH_4Cl at pH 8·5 (Loveday 1974); calcium, magnesium, sodium and potassium in the displaced solution were determined by atomic absorption spectrophotometry.

Table 2. Crop management practices

Soil series (No. of cultivated sites)	Period of cultivation (years)		Cropping intensity (av. number of crops per year)		Rate of fertilizer application (kg ha^{-1} year^{-1})				Stubble retained[B] (% crops/year)		Average cultivation operations per year
					Nitrogen		Phosphorus				
	Range	Mean	Winter crops	Summer crops	Range	Mean	Range	Mean	Range	Mean	
Waco (16)	1–70	26·2	0·6	0·3	0–45	32·6	0–8	1·0	0–100	48·6	5·0
Langlands-Logie (12)	0·5–45	18·0	0·7	0·1	0–30	7·5	0	0	63–100	77·4	4·1
Cecilvale (12)	3–35	18·2	0·6	0·2	0–61	18·3	0–33	7·7	0–100	66·7	4·9
Billa Billa (14)	0·5–25	11·8	0·8	0·1	0	0	0–20	2·0	0–100	72·9	4·8
Thallon (16)	2–23	12·3	0·6	0·1	0[A]	0	0	0	0–100	63·6	3·0
Riverview (13)	0·5–20	7·0	0·5	0·2	0	0	0	0	0–100	13·6	2·9

[A] 12 kg N applied in one year at one site only.

[B] Otherwise burnt (Waco, Langlands-Logie and Cecilvale) or grazed (Billa Billa, Thallon and Riverview).

Nitrate-N was determined colorimetrically (Best 1976) in 2 M KCl extracts obtained from air-dried soil (1:10, soil:solution). Negligible amounts of NH_4-N were present. Biologically mineralizable N was obtained by the procedure described by Keeney (1982). Sodium bicarbonate (pH 8·5) extractable P ($NaHCO_3$-P) (Colwell 1963) and DTPA (diethylenetriaminepentaacetic acid) extractable manganese, zinc and copper were also determined (Lindsay and Norvell 1978).

Urease activity was assayed by the procedure of Douglas and Bremner (1971) by incubating the soil and urea reaction mixture at 37°C for 3 h.

Clay, silt and sands were determined by the pipette method (Day 1965). Also measured were dispersion index [100 × (<2 μm soil dispersed in water after 1 h end-over-end shaking)/total clay, <2 μm)] and aggregation index [100 − (100 × <20 μm soil dispersed in water after 1 h end-over-end shaking)/(total clay + silt, <20μm)]. In Vertisols, the bulk density measured at field moisture content was adjusted for 'normal' shrinkage up to the moisture content at field capacity (Berndt and Coughlan 1976; Yule and Ritchie 1980; Berndt, personal communication).

Statistical Analysis

Overall changes in soil properties were studied by paired '*t*' tests (Snedecor and Cochran 1967), and trends in dry matter yields and N uptake with increasing period of cultivation were determined by regression analysis. Factor analysis, with a varimax rotation of the factors, was used to suggest sources of common variation among the soil properties (Rummel 1970).

Results and Discussion

Changes in Soil Properties

The properties most affected by cultivation in all six soil series were organic C, total N, total C in the light fraction, mineralizable N, DTPA extractable Mn and bulk density (Table 3). The first three properties are components of soil organic matter. Mineralizable N also expresses the biological activity of the soil, and bulk density is one measure of the soil's physical condition. DTPA-extractable manganese probably includes Mn associated with organic matter as well as exchangeable manganese (Randall *et al.* 1976; Shuman 1979). Therefore, those properties affected most by cultivation in these six soils are all associated with soil organic matter. The precise relationship of soil organic matter and its distribution in the light fraction, sand, silt and clay fractions of these soils series with the variable periods of cultivation is examined in detail in subsequent papers.

Overall decline in organic carbon (Table 3) ranged from 19% in Thallon soil to 45% in Langlands-Logie soil; the corresponding total N losses were 25-45%. There were larger losses, however, in total C in the light fraction (25-67%) and mineralizable N (39-57%). Thus, as well as a decline in total quantity of organic matter, the nutrient-supplying capacity decreased at an even faster rate with cultivation. Tiessen and Stewart (1983) showed similar faster declines in labile fractions of organic matter than in total organic matter when virgin soils were cultivated.

The decrease in DTPA-extractable manganese ranged from 25% in Riverview soil to 70% in Cecilvale soil. Overall increase in bulk density ranged from 13% in Riverview soil to 28% in Cecilvale soil (Table 3). Although bulk density measured at a field moisture content was corrected for 'normal' shrinkage in Vertisols from that at field capacity (Berndt and Coughlan 1976; Yule and Ritchie 1980), it is likely that all Vertisols do not shrink normally. However, Coughlan (1984) observed this normal (three-dimensional) shrinkage behaviour in a large number of Vertisols from Darling Downs and central Queensland. As shown later (Table 6), the changes in DTPA-extractable manganese and bulk density upon cultivation were at least partly associated with losses in organic matter upon cultivation.

Table 3. Properties most affected by cultivation in all six soils (0–0·1 m)

Soil property (units)	Waco		Langlands–Logie		Cecilvale		Billa Billa		Thallon		Riverview	
	Original level	% change[A]	Original level	% change[A]	Original level	% change[A]	Original level	% change[A]	Original level	% change[A]	Original level	% change[A]
Organic C (%)	1·63	−28**	2·23	−45**	1·73	−38**	1·48	−34**	0·77	−19**	1·28	−34**
Total N (%)	0·146	−35**	0·204	−45**	0·133	−39**	0·141	−32**	0·064	−25**	0·089	−28**
Total C in light fraction (%)	21·70	−56**	27·10	−62**	20·70	−67**	30·81	−55**	14·60	−51**	30·04	−25*
Mineralizable N (mg kg^{-1})	125·8	−55**	123·5	−57**	98·3	−55**	73·9	−52**	23·8	−39**	30·3	−51**
DTPA-Mn (mg kg^{-1})	24·7	−29**	31·9	−53**	45·4	−70**	22·4	−54**	18·9	−44**	39·7	−25**
Bulk density (Mg m^{-3})	0·84	+20**	0·99	+16**	1·02	+28***	0·94	+15**	0·96	+21**	1·24	+13**

*$P < 0·05$; **$P < 0·01$; according to paired '*t*' test.

[A] 100 × (Mean contents in cultivated soils — Mean contents in corresponding virgin soils)/Mean contents in corresponding virgin soils.

Soil properties moderately affected by cultivation are listed in Table 4. The organic P and total S (inorganic S constituted <10% of total S), oxalate-extractable Fe and DTPA-extractable Cu, generally decreased upon cultivation in at least four soils. The first two are the constituents of soil organic matter (Williams 1962), and the latter two are either chelated or stabilized by organic matter in soil (McKeague and Day 1966; Lindsay and Norvell 1978).

The effect of cultivation on soil pH, exchangeable Mg and oxalate extractable Al did not follow similar trends in all soils (Table 4). Exchangeable Na and exchangeable sodium percentage (ESP) were generally higher in cultivated than virgin soils. This may have been due to changes in cation exchange capacity (Williams 1962), water fluxes, and salt movement in the soils (Shaw and Yule 1978). The significant increases in exchangeable sodium (27–36%) and ESP (27–42%) with cultivation and their future trends require further study because of the likely salinization of soils in semiarid subtropical environments.

Nitrate-N concentration was higher in four of the cultivated soils than in corresponding virgin soils, reflecting the stimulating influence of fallow tillage on N mineralization. Besides, in Waco and Cecilvale soils, nitrate-N concentration may also have been influenced by fertilizer N input. However, the Langlands–Logie soil had a high nitrate-N concentration, even under its native brigalow vegetation (Table 4).

One consequence of the higher mineralizable N in soil, especially in the early years of cultivation, is the rapid increase in nitrate-N content which usually exceeds crop requirements, thus providing the opportunity for surplus nitrate to be leached below the rooting zone (Wetselaar and Norman 1960). This was demonstrated for the Billa Billa soil (Dalal 1984), where nitrate-N accumulated at the rate of 29 kg N ha^{-1} $year^{-1}$ at 0·6–1·2 m depth in the first 12 years of cultivation.

Soil properties generally affected least by cultivation were C/N ratio (except Waco), inorganic P, total K and exchangeable K (except Langlands–Logie), $CaCO_3$ content, dithionite-extractable aluminium, dithionite-extractable iron (except Riverview) and urease activity (except Waco) (Table 5). The effect of cultivation on urease activity in the top layer (0–0·1 m) is complicated by changes in temperature, moisture and substrate (available C) during the year (Dalal 1985).

Clay contents (0–0·1 m) of virgin and cultivated soils were essentially similar in Waco, Thallon and Riverview soils, but they were slightly higher in cultivated Langlands–Logie (49% cf. 52%), Cecilvale (40% cf. 46%) and Billa Billa soils (34% cf. 40%), possibly because deeper soil (0·1 m) was mixed with the topsoil by cultivation or because of removal of topsoil containing lower clay content by erosion. For this reason, and because deeper layers also have effects on crop growth, changes in soil properties with cultivation are considered on the basis of the whole profile in studies to be reported later.

Because of the large number of soil properties measured to discern trends in fertility upon cultivation and cropping, factor analysis was used to suggest sources of common variation among the soil properties (Table 6). The properties were grouped among four factors, factors I, II, III, and IV, representing properties associated with or affected by organic matter, clay and inorganic colloids, iron and aluminium oxides, and soluble salts, respectively, which together accounted for 70% of the total variance. It can be seen from Tables 3 and 6 that factor I, soil

Table 4. Properties moderately affected by cultivation in at least four soils (0–0·1 m)

Soil property (units)	Waco		Langlands–Logie		Cecilvale		Billa Billa		Thallon		Riverview	
	Original level	% change[A]	Original level	% change[A]	Original level	% change[A]	Original level	% change[A]	Original level	% change[A]	Original level	% change[A]
Organic P (mg kg^{-1})	147·0	−29**	208·0	−38**	167·0	−31**	134·0	−34**	113·0	n.s.	92·0	−13*
Total S (mg kg^{-1})	220·0	−29**	373·0	−20*	215·0	−29**	293·0	n.s.	283·0	−36*	119·0	n.s.
pH	8·1	n.s.	7·4	+7**	7·4	−7**	7·4	+7*	7·2	+7*	6·5	n.s.
Exch. Mg (C g^{-1})	27·0	+4*	7·1	+13**	11·0	n.s.	4·9	+16*	8·9	n.s.	1·4	−14*
Exch. Na (C g^{-1})	2·2	+32*	1·1	n.s.	1·1	+36**	1·5	+33*	1·1	+27*	0·04	n.s.
ESP	3·0	+35*	2·5	+36**	3·1	+42**	5·7	n.s.	3·0	+27**	0·3	n.s.
Oxalate-Al (%)	0·36	+4*	0·12	+16**	0·13	+13*	0·07	+44*	0·15	n.s.	0·07	−21*
Oxalate-Fe (%)	0·29	n.s.	0·23	−13**	0·27	−22**	0·12	−21*	0·15	−15*	0·06	−21*
Nitrate-N (mg kg^{-1})	4·7	+470**	9·2	n.s.	1·9	+584**	7·8	+100*	1·2	+367**	2·5	n.s.
DTPA-Cu (mg kg^{-1})	1·5	−12**	1·8	−13**	1·8	−21**	0·8	n.s.	1·0	−12**	0·3	n.s.

$*P < 0·05$; $**P < 0·01$; according to paired '*t*' test. n.s., not significant.

[A] 100 × (Mean contents in cultivated soils − Mean contents in corresponding virgin soils)/Mean contents in corresponding virgin soils.

Table 5. Properties least affected by cultivation in at least five soils (0–0·1 m)

Soil property (units)	Waco		Langlands–Logie		Cecilvale		Billa Billa		Thallon		Riverview	
	Original level	% change^A	Original level	% change^A	Original level	% change^A	Original level	% change^A	Original level	% change^A	Original level	% change^A
C/N ratio	11·2	+12*	11·0	n.s.	13·1	n.s.	10·6	n.s.	12·1	n.s.	14·8	n.s.
Inorganic P (mg kg^{-1})	553·0	n.s.	307·0	n.s.	165·0	n.s.	174·0	n.s.	272·0	n.s.	246·0	n.s.
Total K (%)	0·84	n.s.	0·30	−23**	0·38	n.s.	0·47	n.s.	0·93	n.s.	0·46	n.s.
$CaCO_3$ (%)	0·24	n.s.	1·53	n.s.	0·50	n.s.	1·67	n.s.	1·22	n.s.	0	n.s.
Exch. K (C g^{-1})	2·0	n.s.	1·47	−46*	0·72	n.s.	1·27	n.s.	1·80	n.s.	0·98	n.s.
Dithionite–Al (%)	0·70	n.s.	0·49	n.s.	0·69	n.s.	0·36	n.s.	0·47	n.s.	0·73	n.s.
Dithionite–Fe (%)	1·13	n.s.	0·50	n.s.	0·89	n.s.	0·49	n.s.	0·63	n.s.	1·66	−10*
Urease activity (mg urea-N hydrolysed kg^{-1} soil h^{-1})	72·0	−28*	93·0	n.s.	44·0	n.s.	36·0	n.s.	30·0	n.s.	5·0	n.s.

*$P < 0·05$; **$P < 0·01$; according to paired '*t*' test. n.s., not significant.

^{A} 100 × (Mean contents in cultivated soils — Mean contents in corresponding virgin soils)/Mean contents in corresponding virgin soils.

organic matter, is affected most by cultivation in these soils, and in view of the vital role of organic matter in nutrient element release and maintenance of soil structure, it is clear that the dynamics of organic matter need to be studied in greater detail.

Yield Trends

Total dry matter yield and N uptake by winter cereals (mainly wheat), generally decreased with increasing periods of cultivation (Fig. 2). Significant relationships between the dry matter yield and period of cultivation were obtained in Waco, Billa Billa, Thallon and Riverview soils. The decreases in dry matter yields were 1·8%, 2·3% and 8·5% per year in Waco, Billa Billa and Thallon soils, respectively. In Riverview, a quadratic relationship was obtained, maximum yield being obtained after 3 years' cultivation (Fig. 2). Grain yield trends were essentially similar to those for dry matter, although relationships with period of cultivation were less significant.

Table 6. Factor loadings of selected soil properties (0–0·1 m depth)

Soil property	Factors^A^: I	II	III	IV	Communality
Organic C	0·95				0·96
Total N	0·95				0·95
Organic P	0·73				0·65
Total S	0·57		−0·45		0·59
Mineralizable N	0·88				0·87
$NaHCO_3$-P	0·40	0·30			0·56
DTPA-Cu	0·42	0·52			0·53
DTPA-Zn	0·33				0·38
DTPA-Mn	0·38	−0·33	0·45	−0·31	0·61
Clay		0·95			0·95
Exch. Ca		0·91			0·85
Exch. Mg		0·90	0·30		0·93
Exch. Na		0·71		0·55	0·69
ESP			−0·47	0·67	0·43
EC	0·43			0·77	0·62
pH		0·70		0·43	0·78
Dithionite-Fe			0·85		0·78
Dithionite-Al			0·85		0·69
Inorganic P		0·53	0·34		0·50
Bulk density	−0·43	−0·50			0·56

^A^ Factor loadings ⩾0·30 only are reported. Factors I, II, III and IV, respectively, may be assigned to organic matter, clay and inorganic colloids, iron and aluminium oxides and soluble salts.

Total N uptake also decreased with increasing period of cultivation (Fig. 2). N uptake declined at the rate of 2·3%, 1·7% and 2·4% per year in Waco, Langlands-Logie and Billa Billa soils respectively.

In a study of this nature where crop yields are determined by many factors, it would be difficult to isolate a single factor or group of factors controlling yield (Hallsworth 1969). In the semi-arid environment of the region investigated, water is usually the most limiting factor in crop production. However, in 1983 when the yields in Fig. 2 were obtained, winter rainfall was approximately twice the mean for the study area, and so water would have imposed a less serious limitation on yield. Soil properties, such as nutrient supplying capacity, physical conditions and biological activity (possibly including disease), would have had a clearer influence than usual on yields. Therefore, the general trends towards decreasing yields with increasing period of cultivation (Fig. 2) probably reflects the effect of more dominant soil characteristics on crop yields.

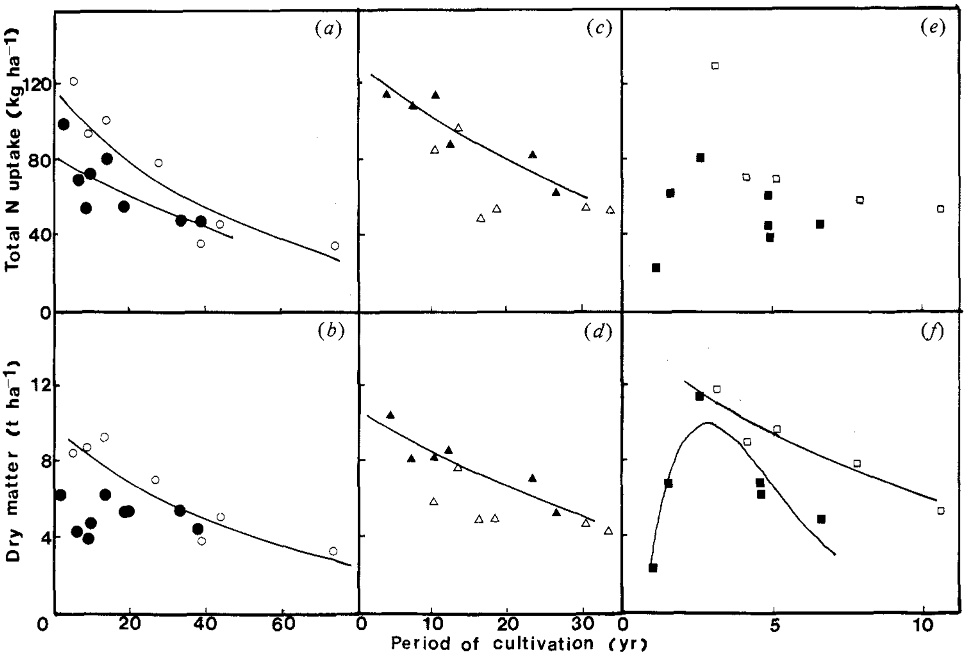

Fig. 2. Total N uptake (N) and dry matter (DM) yields (winter cereals) for 1983 in relation to period of cultivation (x) in six soil series. Symbols are as in Fig. 1. Curves are drawn according to the following regression relationships:
(a) ○ Waco: $y(\mathrm{N}) = 126{\cdot}4\exp(-0{\cdot}023x)$, $r = -0{\cdot}95^{**}$;
(●) Langlands-Logie: $y(\mathrm{N}) = 84{\cdot}4\exp(-0{\cdot}017x)$, $r = -0{\cdot}75^{*}$;
(b) ○ Waco, $y(\mathrm{DM}) = 9{\cdot}84\exp(-0{\cdot}018x)$, $r = -0{\cdot}93^{**}$;
(c) ▲ Billa Billa: $y(\mathrm{N}) = 130{\cdot}4\exp(-0{\cdot}024x)$, $r = -0{\cdot}92^{**}$;
(d) ▲ Billa Billa: $y(\mathrm{DM}) = 10{\cdot}63\exp(-0{\cdot}023x)$, $r = -0{\cdot}89^{*}$;
(e) ☐ Thallon: $y(\mathrm{DM}) = 14{\cdot}43\exp(-0{\cdot}085x)$, $r = -0{\cdot}95^{**}$;
(f) ■ Riverview: $\ln y(\mathrm{DM}) = 2{\cdot}2 + 14{\cdot}9\ln x - 7{\cdot}6(\ln x)^2$; $r = 0{\cdot}91^{**}$;
$^{*}P < 0{\cdot}05$; $^{**}P < 0{\cdot}01$.

Soil properties, such as organic C, total N, total C in light fraction, mineralizable N, DTPA-Mn and bulk density are most affected by cultivation (Table 3 and factor I, and possibly factor III in Table 6). Since these properties also affect crop yields and long-term soil fertility, detailed studies on their dynamics in cultivated soils were undertaken. Further results of this aspect are reported in subsequent papers.

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Appendix 1. Profile morphology (B. Slater, unpublished data)

Billa Billa clay

Depth (mm)	Description
A11 0-50	Greyish yellow brown (10YR4/2); light medium clay; moderate 2-5 mm granular; moderately moist; moderately weak. Field pH 7·5 Clear to —
A12 50-200	Greyish yellow brown (10YR4/2); medium clay; moderate 10-20 mm angular blocky; moist, moderately weak. Clear to —
B21 200-300	Greyish yellow brown (10YR4/2) medium clay; moderate 20-50 mm lenticular; moist, moderately weak. Field pH 8·9. Gradual to —
B22 300-700	As for B21 but includes very few fine carbonate nodules. Field pH 8·0. Gradual to —
B23 700-850	Brown (7.5YR4/3); medium heavy clay; moderate 20-50 mm lenticular; moist, moderately weak. Gradual to —
B24 850-1350	Dull brown (7.5YR5/3); medium clay; moderate 20-50 mm prismatic; moist, moderately weak; very few fine manganiferous veins. Field pH 7·8-7·0. Gradual to —
B25 1350-1500	Dull brown (7.5YR5/4) medium clay; moderate 20-50 mm prismatic; moderately moist, moderately firm; very few fine manganiferous veins. Field pH 6·2.
C1500+	Orange (7.5YR6/7) massive friable sandstone.

Thallon clay

Depth (mm)	Description
A11 0-60	Brownish black (10YR3/2); medium clay; moderate 2-5 mm granular; moist, moderately weak; field pH 8·0. Clear to —
A12 60-200	Greyish yellow brown (10YR4/2); medium clay; moderate 10-20 mm angular blocky; moist, moderately weak. Gradual to —
B21 200-700	Greyish yellow brown (10YR4/2); medium heavy clay; moderate 20-50 mm lenticular; moist, moderately weak. Field pH 8·2-8·8. Gradual to —
B22 700-1000	Greyish yellow brown (10YR5/2); medium heavy clay; moderate 10-20 mm lenticular; moist, moderately weak. Field pH 9·0. Gradual to —
B23 1000-1500	Dull yellowish brown (10YR5/3) medium clay; moderate 20-60 mm prismatic breaking to moderate 20-50 mm lenticular; dry, moderately strong; few fine gypsum crystals. Field pH 8·5-8·0.

Riverview sandy loam

Depth (mm)	Description
A11 0-100	Dark reddish brown (5YR3/4); sandy loam; massive; dry, moderately weak. Field pH 6·0. Diffuse to —
A12 100-180	Dark reddish brown (2.5YR3/3); sandy loam; massive; dry, moderately weak. Clear to —
B21 180-800	Reddish brown (2.5YR4/6); light sandy clay loam; weak 10-20 mm angular blocky; moist, moderately weak. Field pH 5·8-6·0. Gradual to —
B22 800-1050	Reddish brown (2.5YR4/6); sandy clay loam; moist, moderately weak. Field pH 6·2 Diffuse to —
B23 1050-1350	Reddish brown (2·5YR4/6); clay loam, sandy; weak 10-20 mm angular blocky; wet, moderately weak. Field pH 6·2. Gradual to —
C 1350+	Reddish brown (5YR4/6) with orange red and grey mottles; sandy clay — weathered sediments massive; dry, very firm. Field pH 6·8.

Small amounts of fine quartz gravel occur throughout the profile.