Aust. J. Agric. Res., 1995, **46**, 237–53

Effects of Continuous Cultivation on Ferrosols in Subtropical Southeast Queensland. I. Site characterization, Crop Yields and Soil Chemical Status

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Abstract

The productivity of Ferrosols used for rainfed agricultural production in the south and central Burnett regions of south-east Queensland was examined in relation to the duration under continuous cultivation. A range of crops grown in on-farm situations during 1986–90 were examined using paired sites to assess the extent of yield decline with time under cropping. The changes in soil chemical characteristics that have occurred during the cropping period were also assessed.

All locations showed evidence of a significant reduction in crop growth (50–100%) where continuously cropped sites were compared with sites which had either never been cropped or which had been under grazed grass pasture for >20 years. In the absence of severe late season water deficits, this reduced growth rate was always reflected in lower (21–72%) crop yields at maturity. However, crop dry matter (DM) could interact with crop water use under conditions of late-season water deficit to negate, or even reverse, early growth advantages on previously untilled soil.

At least part of the observed yield reduction on continuously cropped soil was due to nutrient deficiencies resulting from depletion of both surface and subsurface reserves during cropping. Long-term cropping has resulted in depletion of soil K and Zn (especially in the subsoil), organic carbon and total N status, and caused significant acidification of both surface and subsoil layers despite the use of lime. The decline in subsoil K status and falling subsoil pH have severe implications for crop performance in dry seasons, when crops rely on subsoil reserves to sustain crop growth. The decline in soil N status has occurred despite a high frequency (>50%) of grain legumes in the crop rotations practised on all farms monitored, and illustrates the small N return from these crops under rainfed conditions.

The reduction in soil organic carbon due to cropping was extreme, with continuously cropped areas having organic carbon levels of only 0·9 to 1·5% in the 0–10 cm layer—values which were only 25–40% of levels in untilled soil. Grazed grass leys were only partly successful in restoration of soil organic carbon status.

Keywords: Ferrosols, chemical status, crop yield, soil fertility, acidification.

Introduction

The inland Burnett districts of Southeast Queensland cover some $2 \cdot 9 \times 10^6$ ha, of which only *c.* 5% is actually used for cropping (Anon. 1990). Nearly 50% (or 60 000 ha) of this cropped area consists of Ferrosol soils (Isbell 1993). Most cropping of Ferrosols occurs in the South Burnett where peanut (*Arachis hypogaea* L.), maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L. Moench),

0004-9409/95/010237$10.00

soybeans (*Glycine max* L.) and winter cereals are commonly grown. The area actually cropped each year fluctuates considerably in response to the amount and distribution of the summer-dominant rainfall, which averages 700–800 mm per annum. Opportunistic double cropping can be undertaken when good soil moisture is available after harvest of the dominant summer crops (Hardman 1985), while irrigated cropping in the area is limited by a lack of above and below ground water supplies. Droughts are a regular occurrence in the area (e.g. shires in the south are drought-declared one year in every five; Vandersee and Kent 1983).

Concerns about declining productivity of the Ferrosol soils used for rainfed row-cropping (especially of the summer peanut crop) have been reported on a number of occasions (Delaney 1978; Loch *et al.* 1987). The extensive surveys undertaken by Delaney (1978) found negative correlations between the yield of peanuts in the 1973 season, and both the frequency of peanut crops in the preceding 10 years and the number of tillage operations used to grow the crop. These data suggested a progressive decline in soil productivity with tillage and peanut cropping. Soil samples taken from the cultivated layer of farms in that survey were analysed for a number of soil physical properties by Loch *et al.* (1987), who concluded that increased peanut cropping frequency caused a progressive reduction in soil organic carbon and mean weight diameter of water-stable aggregates. These effects of peanut cropping frequency were consistent with the relatively low rates of dry matter produced by peanut, compared to other crops, and the intensive tillage associated with peanut cropping at that time (viz. an average of at least 8 tillage operations per crop, excluding planting, for peanut compared with 4 to 5 for other crops; Delaney 1978).

Since the late 1970s, tillage frequency has been reduced somewhat with the widespread adoption of herbicide use, but 4 to 6 tillage operations are still normally undertaken for peanuts and 3 to 5 operations for other crops with the exception of winter cereals, which are often direct-drilled (G. Smith, pers. commun.). However, other problems involving depletion of marginal nutrient reserves (e.g. potassium; Dickson *et al.* 1983) have tended to become more frequent, and the role of compaction and biotic factors (e.g. nematodes, soil insects and soil-borne diseases) in yield limitations on old cropped soil have been identified (McNee *et al.* 1982). Studies have been initiated to examine the role of crop rotations (including grass pasture leys) on productivity of the peanut cropping system (Bell *et al.* 1987). However, no detailed studies on the effect of cropping on the physical and chemical fertility of Ferrosol soils in the region have been undertaken.

The aims of this study were to obtain quantitative data on the 'yield decline' under on-farm conditions, and, by the use of a paired site approach where adjoining areas with differing land use histories (e.g. continuous cropping versus virgin scrub) are compared, assess the impact of rainfed cropping on soil physical and chemical properties which may contribute to any observed yield decline. Bridge and Bell (1994) report the effects of continuous cropping on the physical status of Ferrosols in the inland Burnett. This paper deals specifically with the magnitude of yield decline and the extent of changes in chemical fertility with cropping.

Materials and Methods

Site Selection

Paired sites were selected at three locations in the south and central Burnett districts on soils classified as krasnozems or euchrozems (Stace *et al.* 1968). Site details are provided in Table 1. The Goodger location (krasnozem) was the only place where a reference patch of undisturbed virgin softwood scrub (G_{VS}) was available (beside a stock route which bisected the cropped area). On either side of this virgin area were fields that had been either continuously cropped for >50 years (G_{CC}) or that were in the first year of a return to cropping from a 20-year grazed pasture phase (G_{GL}). Both G_{CC} and G_{GL} had been cropped in a similar fashion prior to the sowing of the pasture in G_{GL}. Monitoring began in the 1988-89 growing season.

The Coolabunia location (euchrozem) had been cleared *c.* 70 years ago. A fenceline separated an area that had undergone continuous cultivation (C_{CC}) from an area that had been maintained as grazed grass pasture adjoining the homestead from clearing until the fence was removed and cropping was commenced in 1987/88 season (C_{VG}). Monitoring was begun at the time of initial cultivation, while a remnant patch of virgin softwood scrub in an adjoining contour bay was also sampled.

The Merlwood location (brown euchrozem) was cleared *c.* 80 years ago. The continuous crop site (M_{CC}) had been cropped continuously since 1915, with the exception of a 5-year period when a lucerne (*Medicago sativa*) ley pasture was established from 1964 to 1969. The grazed pasture area (M_{GL}) had been sown to grass continuously during the period from 1942 to 1986 with the exception of a single year of cultivation in 1970/71. Monitoring was commenced with the return of the M_{GL} area to cropping in 1986/87 season.

Crop Sequences and Cultural Practices

At each location, all sites were sown to similar crop sequences using the normal agronomic practices and cultural operations for each farm. Summer crops consisted of peanut and soybean at Coolabunia, soybean at Goodger and peanut and maize at Merlwood. In all cases, opportunity winter cropping was undertaken to varying extents, dependent on moisture availability. Monitoring was undertaken from 1987/88 to 1989/90 at Coolabunia (4 crops), from 1988/89 to 1990 at Goodger (4 crops) and from 1986/87 to 1989/90 (3 or 4 crops, depending on rotation) at Merlwood. Winter cereals sown during the period were wheat (*Triticum aestivum*) at Goodger and Coolabunia, and triticale (*Triticosecale* spp.) at Merlwood. Winter cereals were grown until grain harvest, rather than ploughed in as green manure.

Farmers at both Coolabunia and Merlwood employed conventional land preparation practices, which typically consisted of primary tillage(s) with offset discs, followed by secondary tillage(s) with tined implements (chisel ploughs or scarifiers) prior to planting of summer crops. Despite use of preplant-incorporated herbicides, inter-row cultivation(s) was generally undertaken. Winter cereals were direct-drilled into summer crop residues using combine seed drills.

The Goodger farmer employed reduced tillage practices which are currently advocated in the region as a means of maintaining surface stubble cover for erosion control. Chisel ploughs and scarifiers (if necessary) were used for primary tillage and seedbed preparation, and inter-row cultivations were kept to a minimum by use of post-emergence herbicide applications. Winter cereals were direct-drilled in similar fashion to the other locations.

Fertilizer applications varied with crop, location and season. Applications made to selected crops during the monitoring period are shown for each location, along with seasonal rainfall totals, in Table 2. The latter refers to rainfall falling between sowing and harvest and can be used as an indicator of seasonal moisture availability. The Merlwood location was unusual in that supplementary irrigation was available from a nearby dam, so the effect of elimination of moisture deficits on relative performance of crops grown on soil with different cropping histories was studied in the 1986-87 summer crop.

Indications of the relative importance of soil nutritional differences in any observed yield depression in continuously cultivated soil were obtained by monitoring tissue nutrient composition (samples of either leaf or whole plant tops, as well as grain composition) and evaluating the impact of increased rates of basal fertilizer application (27 kg P ha^{-1}, 27 kg K ha^{-1}, $0\cdot7$ kg Zn ha^{-1} and $0\cdot24$ kg Mo ha^{-1}) at Coolabunia and Merlwood in 1986/87.

Table 1. Site history, soil classification and particle size distributions for the three monitoring locations

Location	Site designation	Site history	Great Soil Group[A]	Principal Profile Form[B]	Particle size analysis (%) 0–10 cm CS	FS	S	Cl	10–20 cm CS	FS	S	Cl	40–50 cm CS	FS	S	Cl
Goodger	G_{VS}	Virgin softwood scrub	Krasnozem	Uf6·31	11	19	22	48	4	20	17	59	1	9	13	77
(151° 53′ E., 26° 38′ S)	G_{CC}	>50 yr continuous cropping	Krasnozem	Uf6·31	3	19	14	65	2	18	12	68	1	10	8	81
	G_{GL}	Degraded grazed pasture (20 yr) after 30 yrs cropping	Krasnozem	Uf6·31	4	12	15	69	3	12	13	72	2	5	8	85
Coolabunia	C_{VG}	Grazed grass pasture (70 yr), never cropped	Euchrozem	Gn3·12	5	11	16	68	3	12	13	72	1	5	8	86
(151° 53′ E., 26° 36′ S.)	C_{CC}	70 yr continuous cropping	Krasnozem	Uf6·31	3	18	15	64	2	17	14	67	1	10	8	82
Merlwood (151° 53′ E., 26° 30′ S.)	M_{GL}	44 yr grazed grass pasture following 30 yr cropping	Brown Euchrozem	Uf6·31	23	33	12	33	25	30	11	35	17	17	5	59
	M_{CC}	60–70 yr continuous cropping	Brown Euchrozem	Uf6·31	22	21	10	46	30	17	7	46	15	20	11	54

[A] After Stace *et al.* (1968). [B] After Northcote (1979).

Crop Growth and Yield

Sampling for differences in crop growth and yield varied with location and season. Yields at maturity were determined by either harvesting a number of 1 m^2 quadrats (usually 6 to 8) within adjoining areas of differing crop histories (soybeans at Coolabunia and Goodger, wheat at Coolabunia and peanuts at Merlwood), machine-harvesting a number of 10 to 15 m^2 strips within adjoining areas using a small plot combine (triticale at Merlwood), or using commercial yields assessed over larger areas (>5 ha) with similar crop histories determined from weighbridge records.

Table 2. Seasonal rainfall total (including the planting rain event), the number of days upon which ≥5 mm of rain fell, and fertilizer applied for selected crops grown at the locations during the monitoring period

Location	Crop History	Season	Crop	Rainfall (mm)	Rainfall events	Fertilizer applied (kg ha^{-1})[A]
Goodger	G_{GL}	1988–89	Soybean	397	20	125 DAP
	G_{CC}	1988–89	Soybean	397	20	125 DAP
Coolabunia	C_{VG}	1987–88	Peanut	425	18	Nil
		1988–89	Soybean	411	19	125 CK55
		1989	Wheat	186	8	125 CK55
	C_{CC}	1987–88	Peanut	425	18	Nil
		1988–89	Soybean	411	19	125 CK55
		1989	Wheat	186	8	125 CK55
Merlwood	M_{GL}	1986–87	Peanut	284[B]	13	62·5 CK44
		1987	Triticale	243	11	125 DAP
		1987–88	Maize	216	13	30 Urea+125 CK55
		1988–89	Peanut	524	21	62·5 CK44
	M_{CC}	1986–87	Peanut	284[B]	13	62·5 CK44
		1987	Triticale	243	11	125 DAP
		1987–88	Maize	216	13	30 Urea+125 CK55
		1988–89	Peanut	524	21	62·5 CK44

[A] Fertilizer sources:
DAP: 19% N, 20% P, 3% S.
CK55: 14% N, 14·7% P, 12·3% K, 2·2% S.
CK44: 8·7% N, 9·1% P, 26·2% K, 1·4% S.
Urea: 46% N.
[B] Irrigated plots received six supplementary irrigations totalling 180 mm.

Above-ground dry matter (DM) was measured by destructive sampling from a number of 1 m^2 sample quadrats, with sampling undertaken either at regular intervals (e.g. every 14 to 21 days; Merlwood in 1986/87) or at key phenological stages (e.g. anthesis in wheat at Coolabunia and triticale at Merlwood; 50% flowering in soybeans at Goodger and Coolabunia).

Plant Tissue Analyses

Plant tissue analyses for essential nutrients varied with location and crop as follows: peanut leaf samples (youngest fully expanded leaflets) sampled within 1 to 2 weeks of flowering at Merlwood in 1986–87; whole plant samples of wheat at anthesis and soybeans at flowering from Coolabunia in 1989; whole plant samples of soybeans at flowering from Goodger; analyses of grain protein content (wheat at Coolabunia) and elemental composition (maize and triticale at Merlwood) were also undertaken.

Samples were dried at 65°C, ground to <1 μm and pelleted prior to analysis for K, Ca, Mg, Na, Cl, Mn, Zn and Cu by X-ray fluorescence, using a Trail-Lachance correction model (Lachance and Trail 1966) and mass absorption coefficient data from Champion *et al.* (1968). Separate samples of finely ground material were analysed for N and P using a semi-micro Kjeldahl digestion procedure.

Soil Sampling for Nutrient Analyses

Regular sampling of soil was undertaken at all locations during the monitoring periods, and in the case of both Goodger and Coolabunia, monitoring has continued until 1993–94 season. Soils were sampled to at least 100 cm during site characterization, with subsequent samplings generally restricted to the top 40 or 60 cm. Soil samples were analysed using methodology described by Rayment and Higginson (1992). Briefly, soil pH, EC and NO_3-N were determined in a 1:5 soil:water suspension. Exchangeable cations were extracted with 1 M NH_4Cl (pH 7·0) and effective cation exchange capacity (ECEC) determined from the sum of exchangeable Ca, Na, K and Mg. Organic C was determined using the Walkley and Black procedure and total N was measured by Kjeldahl digestion. Phosphorus and Zn were determined after extraction with 0·5 M $NaHCO_3$ and DTPA, respectively. Not all analyses were undertaken on all samples or on all depths (e.g. organic carbon and total N analyses were only undertaken on soil from the top 20 to 30 cm of the profile).

Statistical Analyses

Paired t-tests were used to indicate significant differences in soil chemical properties between sites for each depth at each location, and in crop yields at both Coolabunia and Goodger. Fully replicated ($n = 3$) split plot experiments were established on both the M_{GL} and M_{CC} sites to examine the role of irrigation (main plots) and agronomic variables (plant population, fertilizer; subplots) on crop growth and yield. Analyses of variance were undertaken on crop yield and quality data for each of M_{GL} and M_{CC}. Homogeneity of error variance, indicated by nonsignificant Bartlett's tests, allowed data from the two sites to be subsequently pooled for a combined analysis of the interaction between site history and applied treatments on yield and quality.

Results

Soil Chemical Changes with Cropping

Soil chemical characteristics in the top 30 cm of the profile differed markedly with site history at each location (Table 3). In particular, organic carbon (OC) and total N contents had declined sharply with cropping (especially in the 0–10 cm layer), while the bicarbonate-extractable P content was greatly increased under cropping. In addition, there were also substantial declines in soil-extractable Zn content (especially at Goodger), in pH (at Coolabunia and Goodger) and in ECEC at all locations in the continuous crop sites.

Long periods of grass pasture leys on previously cropped soils at both Goodger and Merlwood produced some significant changes in chemical characteristics compared to continuous cropping. Both OC and total N contents were higher under the ley pasture system, and ECEC was also notably higher. There was also a tendency for higher soil mineral N in the grass areas. At Goodger, where both a soil in virgin condition and one returning to crop after a grass ley were present, it should be noted that the grass ley did not allow recovery of any component of surface chemical fertility to near the original virgin levels.

The changes in organic carbon in the 0–10 cm layer with clearing and sowing grass pasture, or with the duration of cultivation at Coolabunia are shown in Fig. 1. Equilibrium organic carbon levels under uncultivated grass pasture were approximately half that under virgin scrub—a finding similar to that recorded by Moody (1994) from a collection of Australian Ferrosols with a variety of land uses.

Table 3. Effects of cropping history on selected soil chemical characteristics in the top 30 cm of the soil profile

Data are presented as means (with associated s.e.); the number of samples are shown

	0–10	10–20	20–30	0–10	10–20	20–30	0–10	10–20	20–30
Goodger ($n = 4$)	Virgin softwood scrub (G_{VS})			Continuous cultivation (G_{CC})			Grazed grass ley (G_{GL})[A]		
pH	6·1 (0·4)	6·7 (0·3)	6·7 (0·4)	5·4 (0·1)	5·1 (0·1)	5·2 (0·3)	6·5 (0·1)	6·4 (0·2)	6·5 (0·1)
Org. carbon (%)	4·8 (0·6)	2·4 (0·2)	1·4 (0·1)	1·3 (0·1)	1·0 (0·1)	0·7 (0·1)	2·6 (0·4)	1·5 (0·1)	1·1 (0·2)
Total N (%)	0·43 (0·04)	0·24 (0·01)	0·16 (0·01)	0·17 (0·01)	0·14 (0·01)	0·11 (0·01)	0·23 (0·01)	0·18 (0·02)	0·13 (0·03)
ECEC (cmol kg^{-1}	18·5 (2·5)	10·7 (2·2)	9·5 (1·6)	8·1 (0·2)	7·7 (0·4)	8·5 (0·9)	11·5 (0·5)	10·4 (0·3)	10·0 (0·4)
NO_3–N (ppm)	4·0 (2·7)	1·5 (0·3)	2·8 (1·0)	4·3 (0·8)	10·0 (2·0)	8·3 (1·1)	9·0 (4·1)	18·3 (7·1)	12·0 (5·1)
Bicarb. P. (ppm)	14·5 (4·8)	4·8 (1·4)	3·3 (0·8)	72·8 (3·5)	38·5 (2·9)	9·8 (1·1)	17·8 (1·9)	8·5 (0·5)	4·0 (0·4)
Extract. Zn (ppm)	14·5 (4·9)	4·7 (1·2)	1·5 (0·6)	3·3 (0·8)	2·0 (0·7)	0·5 (0·3)	4·3 (0·7)	2·3 (0·9)	1·2 (0·6)
Coolabunia ($n = 3$)	Grazed grass pasture, never cropped (C_{VG})[B]			Continuous cultivation (C_{CC})					
pH	6·8 (0·1)	7·0 (0·1)	7·2 (0·2)	6·5 (0·2)	6·3 (0·1)	6·1 (0·3)			
Org. carbon (%)	3·8 (0·2)	1·6 (0·1)	1·1 (0·1)	1·5 (0·2)	1·1 (0·1)	0·9 (0·2)			
Total N (%)	0·35 (0·01)	0·19 (0·01)	0·13 (0·01)	0·15 (0·01)	0·10 (0·01)	0·08 (0·01)			
ECEC (cmol kg^{-1})	15·3 (0·6)	11·2 (0·9)	10·2 (0·6)	9·1 (0·1)	8·7 (0·7)	8·8 (1·0)			
NO_3–N (ppm)	1·3 (0·3)	1·7 (0·7)	4·7 (2·7)	1·0 (0·0)	3·3 (2·3)	6·0 (4·5)			
Bicarb. P. (ppm)	9·5 (1·3)	3·0 (0·8)	1·3 (0·3)	39·3 (1·1)	6·8 (0·8)	2·3 (0·3)			
Extract. Zn (ppm)	6·5 (0·4)	0·8 (0·2)	0·4 (0·2)	2·7 (0·3)	0·7 (0·2)	0·6 (0·1)			
Merlwood ($n = 3$)				Continuous cultivation (M_{CC})			Grazed grass pasture ley (M_{GL})[B]		
pH				7·0 (0·5)	7·0 (0·5)	6·8 (0·4)	6·8 (0·1)	6·8 (0·1)	7·1 (0·2)
Org. carbon (%)				0·9 (0·1)	0·9 (0·1)	0·7 (0·2)	1·6 (0·3)	1·6 (0·2)	1·1 (0·1)
Total N (%)				0·09 (0·01)	0·09 (0·01)	0·08 (0·01)	0·17 (0·1)	0·16 (0·1)	0·14 (0·1)
ECEC (cmol kg^{-1})				11·0 (0·1)	11·1 (0·3)	15·3 (0·4)	12·5 (0·6)	12·0 (0·3)	13·6 (0·3)
NO_3–N (ppm)				7·0 (2·0)	8·0 (1·1)	4·8 (1·2)	12·5 (2·6)	20·0 (1·4)	13·0 (2·2)
Bicarb. P (ppm)				26·3 (3·9)	33·0 (4·1)	12·6 (2·1)	14·5 (2·9)	17·0 (1·2)	9·0 (1·1)
Extract. Zn (ppm)				1·6 (0·3)	ND[C]	ND	3·8 (1·3)	ND	ND

[A] Sampled prior to initial cultivation. [B] Sampled after initial cultivation. [C] Not determined.

The observed change in organic carbon with duration of cropping is in good agreement with the relationship established by Briggs (1970; Fig. 1) from survey data collected across the South Burnett, despite extension of the cultivated period to *c.* 70 years. Data highlight the rapid decline in organic matter during the initial years of cropping. Data for the 10–20 cm and 20–30 cm layers also show the beginning of a similar rapid rate of decline in organic carbon (data not shown), although only after levels had initially doubled (from $1 \cdot 60 \pm 0 \cdot 06$ and $1 \cdot 10 \pm 0 \cdot 06$ % to $3 \cdot 03 \pm 0 \cdot 26$ and $2 \cdot 10 \pm 0 \cdot 21$ % for the 10–20 cm and 20–30 cm levels, respectively) in response to the mixing associated with the first year of cultivation.

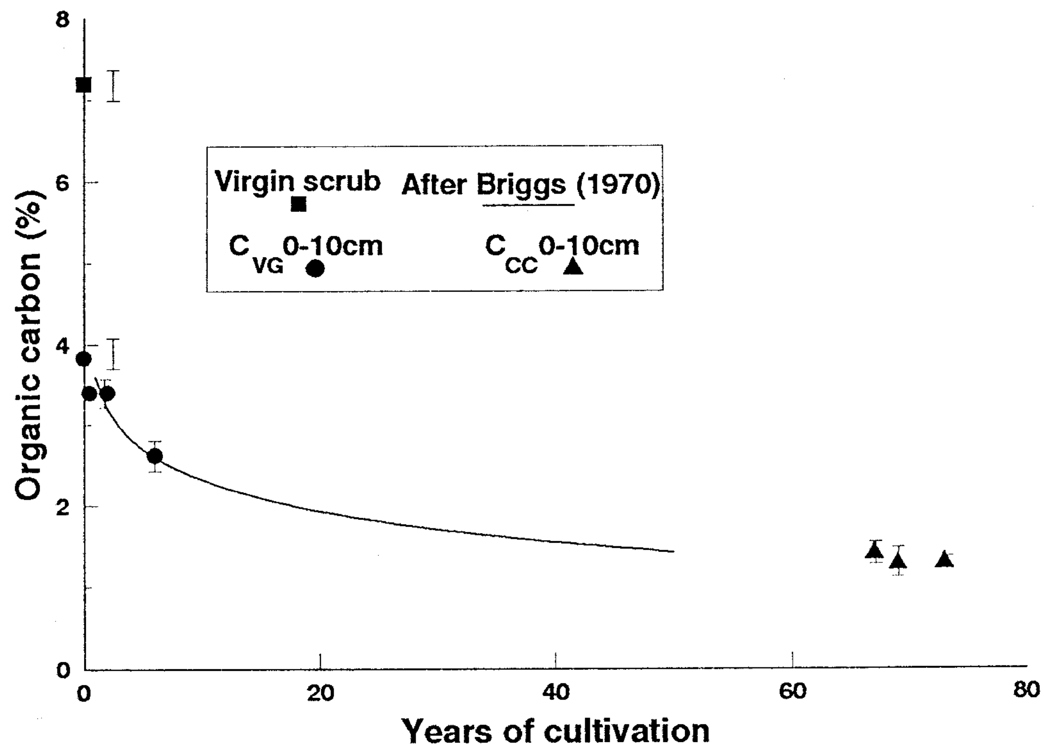

Fig. 1. Changes in soil organic carbon content (0–10 cm) as a function of the length of the cultivation period in an area continuously cropped for 70 years (C_{CC},) and in an area of grass pasture (C_{VG}) first cropped in 1987–88 at Coolabunia. Data are shown for sampling over the period 1988 to 1993, with vertical bars indicating standard errors for each sample occasion. The relationship (solid line) obtained by Briggs (1970) from a survey of South Burnett farms is also shown.

In addition to the changes in surface chemical fertility resulting from cropping indicated in Table 3, there were also large changes in exchangeable cations (especially K content) and significant changes in soil pH deeper in the profile (Fig. 2 and Fig. 3, respectively). The exchangeable K data shown for the Coolabunia location (Fig. 2) were typical of the trends shown with long-term cropping across the other locations (data not shown). There are two notable aspects of the effects of cropping on soil K status as indicated in Fig. 2. The first is the large reduction in exchangeable K status with cropping, especially in the surface soil layers, whilst the second is the apparent concentration of a large proportion of the total soil exchangeable K reserves near the soil surface. This marked stratification of nutrient reserves has particular significance in rainfed conditions where the surface layers are often dry for long periods during a growing season and hence water and nutrient uptake must come from reserves deeper in the profile.

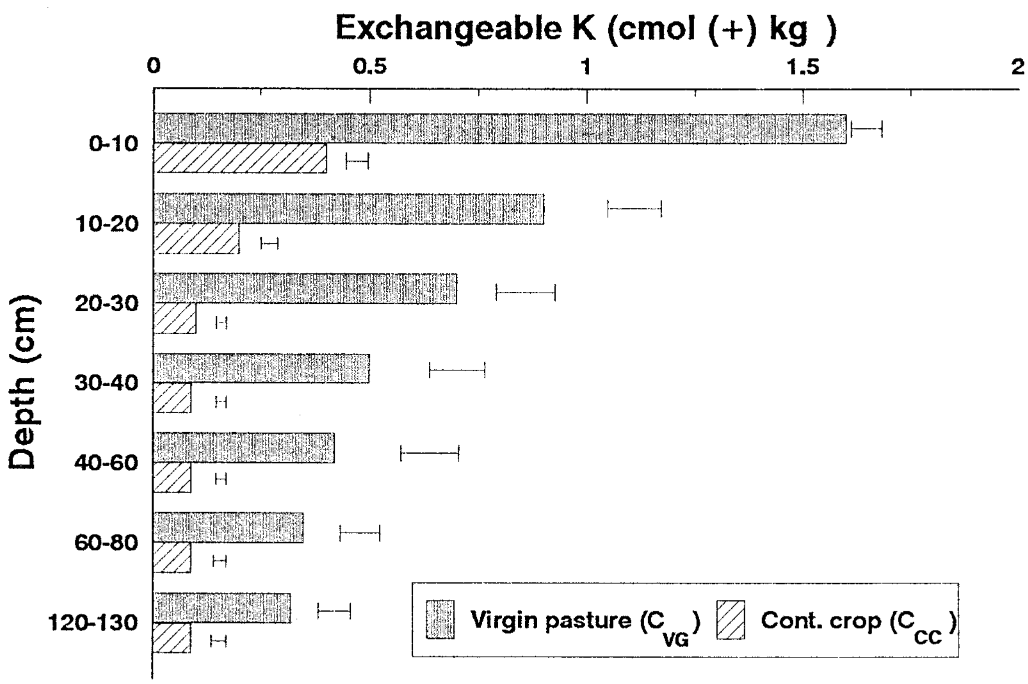

Fig. 2. Effects of cropping history on the soil exchangeable K (cmol(+) kg^{-1}) with depth for cultivation with a prehistory of either virgin grass pasture (C_{VG}) or continuous cropping (C_{CC}) at Coolabunia prior to the 1987–88 summer season. Vertical bars indicate standard errors at each depth for each prehistory ($n = 3$).

The trend for acidification of the profile with cropping seen at Goodger (Fig. 3) and Coolabunia was not evident at all at Merlwood (data not shown). The lack of substantial acidification at this location may have been due, in part, to lime applications resulting from an extensive program of fertility monitoring of surface soil undertaken as part of the PADFERT program (Vance and Ada 1989). However, it should be noted that, despite periodic applications of 3–5 t lime ha^{-1}, reductions in pH at Goodger and Coolabunia were still recorded (Table 3, Fig. 3).

Effects of Site History on Crop Dry Matter Production

Crop dry matter (DM) data are shown for peanut, soybean, wheat and triticale crops at key phenological stages from Coolabunia and Merlwood in Table 4. In all cases, there was evidence of a significant reduction in crop DM on continuously cultivated soil, with the magnitude of the reduction at least partially overcome by the application of supplementary irrigation at Merlwood.

Increased rates of basal fertilizer, tested at both Coolabunia and Merlwood, produced no significant changes in crop yield in either 1986–87 or 1987–88, although effects on DM production were not assessed. Final crop yields in Table 5 therefore represent means across both fertilizer regimes at both locations. Crop yields generally show a similar advantage of grass ley or virgin sites over continuously cropped sites, although the relativities for final yield were generally less than those recorded for crop DM at earlier stages of growth. However, in the extreme cases of the 1989 wheat crop at Coolabunia and the 1987–88 maize and peanut crops at Merlwood (Table 5), early season growth advantages were negated by severe water deficits late in the season. These severe water deficits affected the larger, more vigorous canopies first in that they more rapidly exhausted available soil moisture reserves (Bridge and Bell 1994). Similar observations were made with a later-maturing peanut cultivar at Merlwood in 1986/87 (Bell *et al.* 1989).

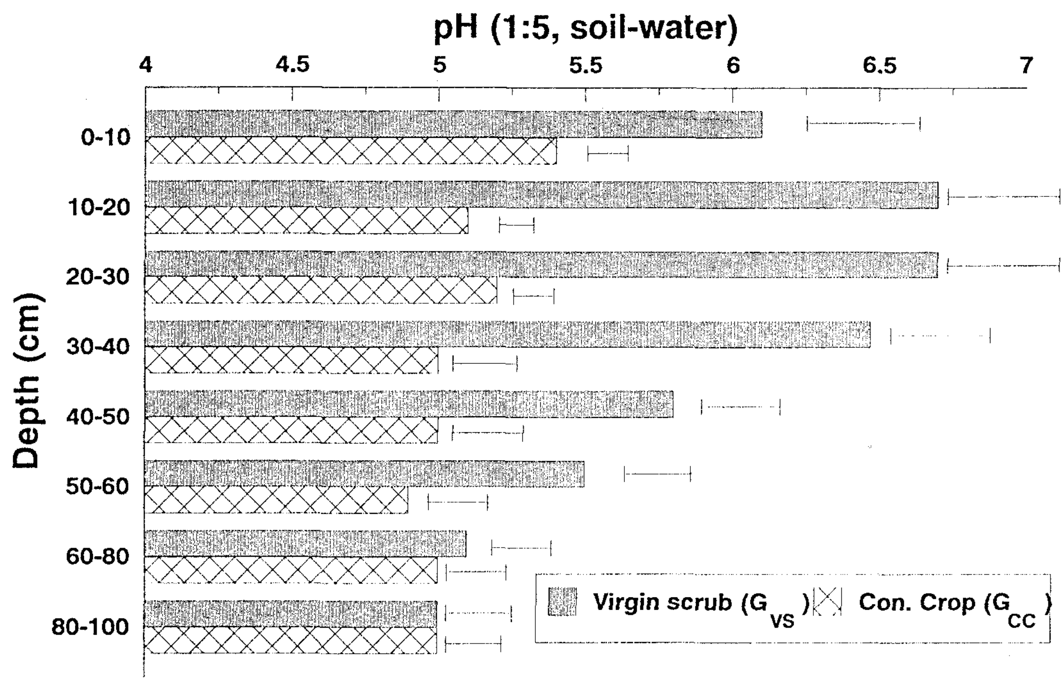

Fig. 3. Effects of site history on soil pH (1:5, soil-water) with depth at Goodger for either virgin softwood scrub (G_{VS}) or continuous cropping (G_{CC}) prior to the 1989–90 summer season. Vertical bars indicate standard errors at each depth for each prehistory ($n = 4$).

Table 4. Effects of cropping history on dry matter (DM) at key phenological stages for peanut (beginning podfill), soybean (flowering), wheat and triticale (anthesis) crops grown at Coolabunia and Merlwood

Different letters indicate significant (0·05) differences between sites within crop/year/location combinations

Crop	Year	Location	Site history	Rainfed DM (kg ha^{-1})	Irrigated DM (kg ha^{-1})
Peanut	1986–87	Merlwood	M_{GL}	6215a	5880a
			M_{CC}	3762c	4952b
Triticale	1987	Merlwood	M_{GL}	3253b	4354a^{A}
			M_{CC}	1687c	3074b^{A}
Soybean	1988–89	Coolabunia	C_{VG}	4500a	—
			C_{CC}	3260b	—
Wheat	1989	Coolabunia	C_{VG}	8620a	—
			C_{CC}	5840b	—

^{A} Represents residual soil moisture from the irrigated peanut crop in 1986–87, which amounted to *c.* 30 mm in M_{GL} and 70 mm in M_{CC} in the top 140 cm of the soil profile. Gravimetric samples were taken at sowing of the triticale crop.

Role of Nutrient Deficiencies in Crop Response

The effects of cropping history on nutrient composition of plant tissue at various growth stages at Coolabunia and Merlwood are shown in Table 6, with the most notable features being the reduction in tissue K concentration (especially in peanut leaf and whole soybean plant samples) and grain protein content of the cereal crops with continuous cropping. Data suggest that K status of the Coolabunia continuous crop site was marginal for peanut (Jones 1974) and soybeans sown in the subsequent summer season also showed large differences in whole plant K concentration at flowering, despite applications of 15 kg K ha^{-1} as a basal dressing. The K status of the Merlwood sites was higher, but plant K status was still depressed with continuous cultivation.

Table 5. Effects of cropping history on yields of peanut, soybeans, wheat, triticale and maize at various locations

Different letters indicate significant (0·05) differences between sites within crop/year/location combinations; ns (not significant)

Crop	Year	Location	Site history	Rainfed	Irrigated
				Yield (kg ha^{-1})	
Peanut	1986–87	Merlwood	M_{GL}	2348c	4237a
			M_{CC}	1563d	3052b
	1987–88	Coolabunia	C_{VG}	1510a	—
			C_{CC}	420b	—
		Merlwood	M_{GL}	670 (ns)	—
			M_{CC}	820	—
	1988–89	Merlwood	M_{GL}	900 (ns)	—
			M_{CC}	754	—
Triticale	1987	Merlwood	M_{GL}	838bc	1690a[A]
			M_{CC}	620c	1100b[A]
Maize	1987–88	Merlwood	M_{GL}	2930 (ns)	—
			M_{CC}	3370	—
Soybean	1988–89	Coolabunia	C_{VG}	2900a	—
			C_{CC}	2310b	—
		Goodger	G_{GL}	2560 (ns)	—
			G_{CC}	2020	—
Wheat	1989	Coolabunia	C_{VG}	2920b	—
			C_{CC}	3820a	—

[A] Represents residual soil moisture from irrigated peanut crop in 1986–87, which amounted to *c*. 30 mm in M_{GL} and 70 mm in M_{CC}.

The decline in grain protein with cropping in the winter cereal crops at both locations was not unexpected owing to the low soil mineral N status and the relatively low rates of fertilizer applied at sowing. The difference between sites at Coolabunia was exacerbated by the extremely dry finish to the growing season which, although resulting in relatively small seed sizes at both sites, contributed to the large differences in 1000 grain weight between the C_{VG} and C_{CC} crops (viz. 20·1 and 35·4 g 1000 $seeds^{-1}$ in C_{VG} and C_{CC}, respectively). The relative inability of the C_{VG} site to adequately fill established seeds resulted in an increased concentration of abundant crop N reserves in the grain. However, despite the poor seed filling which also occurred (to a lesser extent) at the C_{CC} site, grain N content was still in the range considered to be indicative of N deficiency (Strong 1981).

Table 6. Effects of site history on selected nutrient concentrations of peanut, wheat, maize and soybean crops at Coolabunia and Merlwood

Values are shown as means (with associated s.e.); the number of samples (n) is shown

Location	Crop/season	Site history	Plant part/age	Nutrient concentration			
				N (%)	P (%)	K (%)	Zn (mg kg^{-1})
Coolabunia	Peanut 1987–88	C_{VG}	FEL[A] (flowering)	5·0 (0·3)	0·41 (0·02)	3·81 (0·22)	47·6 (4·2)
	($n = 8$)	C_{CC}	FEL[A] (flowering)	5·2 (0·2)	0·42 (0·02)	2·12 (0·47)	42·5 (2·1)
	Soybean 1988–89	C_{VG}	Whole plant (flowering)	3·0 (0·1)	0·15 (0·01)	2·33 (0·10)	32·5 (1·9)
	($n = 3$)	C_{CC}	Whole plant (flowering)	2·4 (0·2)	0·14 (0·01)	1·57 (0·10)	25·9 (1·8)
	Wheat 1989	C_{VG}	Grain (harvest)	2·8 (0·1)[B]	—	—	—
	($n = 4$)	C_{CC}	Grain (harvest)	1·6 (0·1)[B]	—	—	—
Merlwood	Peanut 1986–87[C]	M_{GL}	FEL[A] (flowering)	5·4 (0·2)	0·47 (0·03)	3·92 (0·13)	50·0 (3·8)
	($n = 16$)	M_{CC}	FEL[A] (flowering)	5·5 (0·2)	0·47 (0·03)	3·26 (0·24)	44·4 (4·1)
	Triticale 1987	M_{GL}	Grain (harvest)	2·37 (0·15)	0·23 (0·02)	0·47 (0·01)	52·4 (4·2)
	($n = 4$)	M_{CC}	Grain (harvest)	1·89 (0·22)	0·32 (0·04)	0·52 (0·03)	48·1 (4·4)
	Maize 1987–88	M_{GL}	Grain (harvest)	1·80 (0·09)	0·29 (0·02)	0·38 (0·01)	22·1 (0·6)
	($n = 4$)	M_{CC}	Grain (harvest)	1·71 (0·04)	0·28 (0·01)	0·36 (0·01)	20·0 (0·4)

[A] Newest fully expanded leaflets at the top of the canopy.
[B] Assuming 1% N = 6·25% crude protein.
[C] Values represent means across cultivars and irrigation treatments.

Despite evidence of reduced tissue Zn concentrations at both continuous crop sites, all tissue values were within the range considered to be adequate for crop growth (Jones 1974).

Discussion

Crop growth and yield data have confirmed the existence of 'yield decline' on cropped Ferrosol soils in the South and Central Burnett, although the extent of the decline seems largely dependent on the timing and severity of any water stress events (Tables 4 and 5). The relatively high frequency of occurrence of water deficits in the inland Burnett region may at least partly explain the lack of attention paid to this problem in the past. In all crops examined in these studies, DM was greatly reduced on soils with a long history of continuous cropping compared to sites that were either in virgin condition or returning to cropping after a long period of grass ley. However, the ability of these more vigorous crops to convert increased early growth into a yield advantage at maturity was often influenced by the availability of soil water reserves and the occurrence of rainfall late in the season. Extensive monitoring of soil moisture reserves at both Coolabunia and Merlwood (Bridge and Bell 1994) have shown that crops on the undegraded soil were better able to exploit stored soil water for crop growth, but that as a consequence, soil reserves were more rapidly and completely exhausted during dry periods. This was of particular importance during terminal stress conditions which occurred at Coolabunia in 1989 and Merlwood in 1987 and 1987–88, when soil moisture reserves were exhausted early in the grain filling process.

Despite the observations by Bridge and Bell (1994) that crops grown on degraded cropping soils were less able to exploit available soil moisture reserves, provision of water with supplementary irrigation at Merlwood was unable to compensate for other soil limitations. Peanut yields were 39% and 50% greater on the pasture ley soil with and without irrigation, respectively (Table 5). These differences occurred despite the use of acceptable crop rotation practices for the control of soil-borne pathogens on the continuously cropped sites at all locations (McNee *et al.* 1982; Bell *et al.* 1987), and were not due to any differences in established plant population or differences in plant mortality during the season.

The relative importance of nutrient deficiencies in the observed yield decline on old cropped soils is unclear, especially for the legume crops at Coolabunia and Goodger. There were strong indications of N limitations to the yield of the Coolabunia wheat crop on old cropped soil (Table 6) which were consistent with the observed decline in soil N status (Table 3; Strong 1981). Such declines in soil N status with duration of cropping have been at least partly responsible for the observed trend of declining productivity on other soil types (e.g. Vertisols on the Darling Downs of southern Queensland: Dalal and Mayer 1986*a*). However, the role of soil N status in the yield of legume crops like soybeans and peanuts has not been well established in this environment. For example, Diatloff and Langford (1975) and Peoples *et al.* (1992) found no response to fertilizer N for yield of peanut crops on soils in this region. This was despite the fact that the study by Peoples *et al.* (1992) included crop rotation treatments which caused total soil N levels, determined immediately prior to planting, to vary by 25 to 40% in different seasons.

The role of depleted soil K status is of much greater concern at all locations, particularly with the concentration of a high proportion of the exchangeable K near the soil surface (Fig. 2). These soils contained only moderate levels of K in their virgin condition due to the intensely weathered nature of the parent material (Vandersee and Kent 1983). Our data suggest that cropping during the last 60 years has seriously depleted these reserves and will necessitate a more widespread use of K fertilizers than that envisaged by Dickson *et al.* (1983). However, the rates of K applied seldom represent replacement of K removed in grain. For example, Burnett peanut crops remove an average of 10 kg K ha^{-1} $tonne^{-1}$ pods (district average yield of $1 \cdot 2$ t ha^{-1}) and 20 kg K ha^{-1} $tonne^{-1}$ hay, with the sale of hay made from crop residues after harvest a means of supplementing income in drier years (Crosthwaite and Harvey 1993). In addition, distribution of remaining K reserves is such that K is often unavailable for prolonged periods owing to its concentration in drier layers close to the soil surface. Transient K deficiency symptoms are being reported more frequently, especially from farms which are adopting reduced tillage practices which promote the use of tined implements and minimize deep ploughing and soil inversion (Vance 1989).

Tissue analyses (Table 6) and soil test results (Table 3) suggest that the M_{CC} site was not suffering K deficiency. However, we were unable to assess the role played by K deficiency in limiting the yields of the successive wheat and soybean crops on old cropped soil at Coolabunia and Goodger. Applications of K were made in the basal fertilizer mix for each crop at Coolabunia (Table 2), but there was still a large difference in the K concentration of soybean plants at flowering, compared to those grown on the uncultivated site (Table 6). Leaf K concentrations of peanut leaves grown on the same sites at Coolabunia in 1987–88 (Table 6) showed similar large differences in tissue K concentration between crop histories and indicated that K status on the cropped soil was marginal (Jones 1974). The lack of yield response to the additional applications of $27 \cdot 4$ kg K ha^{-1} side-dressed at peanut planting in small subplots at Coolabunia in 1987–88 may have been a function of the low availability of basal fertilizers in dry surface soil layers rather than an indication of adequate soil K for crop growth. Further work on K status at these sites is planned.

The significance of the acidification of both Goodger (Fig. 3, Table 3) and Coolabunia (Table 3) is difficult to interpret in the light of the periodic use of surface applications of lime on all locations in this study. The low pH recorded at depth in the continuously cropped site at Goodger is likely to restrict root development in deeper layers of the profile but the effects at Coolabunia, while still substantial, are unlikely to limit crop growth. The importance of regular lime applications to prevent soil acidification on Ferrosol soils in the region has been recognized (Aitken *et al.* 1991; Moody and Aitken 1994; Moody *et al.* 1994), and data presented here suggest that methods of addressing subsoil acidity in old cropped soil need to be developed.

The extremely low levels of organic carbon found in the continuously cropped soils at all locations (Table 3), and the rapid decline in organic carbon levels under cropping observed at the Coolabunia (C_{VG}) site (Fig. 1) have serious implications for both nutrient availability and for soil physical condition. The substantial reduction in ECEC on all cropped soils (Table 3) reflects the importance of organic carbon in determining ECEC in these soils (Isbell *et al.* 1976). However, whilst this decline in ECEC and losses in nutrients (e.g. K, Fig. 2) are of significance, it is the loss of soil structural stability that is likely to accompany such organic matter decline (Douglas and Goss 1982; Loch *et al.* 1987; Bridge and Bell 1994) which is of greatest concern. The large-scale losses of organic carbon that have occurred with cropping have been shown to lead to increased surface sealing and reduced infiltration under rain (Loch *et al.* 1987; Bridge and Bell 1994)—factors which are of considerable significance in determining seasonal crop yield potential in this unpredictable rainfed environment. These aspects of structural stability and rainfall infiltration are addressed in detail elsewhere (Bell *et al.* 1994; Bridge and Bell, 1994).

The extent of the decline in organic carbon evident with cropping (i.e. when comparing cropped and uncropped sites) is greater than that recorded in Vertisols by Dalal and Mayer (1986*b*) and Chan *et al.* (1988), but is similar to that recorded on Oxisol soils in Brazil under conventional cropping by Machado and Gerzabek (1993). The cultural practices and crop rotations at each cropped site, although differing between locations, have remained relatively constant for the last 10–15 years. Hence it is reasonable to assume that the measured organic carbon levels represent near-equilibrium values for the respective cropping systems at each location. It is therefore interesting to note the similarity in those organic carbon levels (0·9 to 1·5%; Table 3) despite major differences in tillage system and crop rotation between locations. For example, reduced tillage is practiced at Goodger, versus more conventional tillage at Merlwood and Coolabunia, and peanut does not form part of the rotation at Goodger, whilst at Coolabunia and Merlwood peanut is generally grown every second summer in rotation with corn or soybeans.

Loch *et al.* (1987) concluded that organic carbon levels in these soils could be increased by reducing the frequency of peanut crops in the rotation or by a reduction in the number and severity of tillage operations. However, our data suggest that both the absence of peanut from the crop rotation and the adoption of reduced tillage at Goodger have had little impact on equilibrium organic carbon levels compared to locations with similar soil, but more conventional rotations and tillage practices (e.g. Coolabunia: Table 3). This result was also unexpected on the basis of results from other long-term rotation studies (M. J. Bell, unpublished data). However, it is possible that poor physical condition of the cropped soil at Goodger (Bridge and Bell 1994), combined with the problems of poor nutrient distribution shown in Fig. 2, have resulted in lower rates of DM production under reduced tillage compared with that under conventional tillage systems. This may therefore have countered the advantages conferred by growing crops which generally produce higher levels of DM than peanut (Loch *et al.* 1987; M. J. Bell, unpublished data) in the rotation. Further studies on these aspects of the cropping systems are warranted.

Acknowledgments

The authors are thankful for the kind permission of Mr R. K. Buttsworth (Goodger), Mr J. Larsen (Coolabunia) and Mr B. Richards (Merlwood) to monitor soil condition and crop performance on their properties over a number of years. Without their assistance none of this work would have been possible. In addition, the assistance and advice of Mr P. Moody, Mr R. Aitken, Mr P. Vance, Mr I.

Crosthwaite and Mr P. Sorby is gratefully acknowledged, as is the field assistance of Mr W. Tapsall and staff of the J. Bjelke Petersen Research Station, Kingaroy.

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Manuscript received 18 July 1994, accepted 12 September 1994