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No-tillage and nitrogen application affects the decomposition of ^{15}N-labelled wheat straw and the levels of mineral nitrogen and organic carbon in a Vertisol

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Abstract. No-tillage (NT) practice, where straw is retained on the soil surface, is increasingly being used in cereal cropping systems in Australia and elsewhere. Compared to conventional tillage (CT), where straw is mixed with the ploughed soil, NT practice may reduce straw decomposition, increase nitrogen immobilisation and increase organic carbon in the soil. This study examined ^{15}N-labelled wheat straw (stubble) decomposition in four treatments (NT *v.* CT, with N rates of 0 and 75 kg/ha.year) and assessed the tillage and fertiliser N effects on mineral N and organic C and N levels over a 10-year period in a field experiment.

NT practice decreased the rate of straw decomposition while fertiliser N application increased it. However, there was no tillage practice × N interaction. The mean residence time of the straw N in soil was more than twice as long under the NT (1.2 years) as compared to the CT practice (0.5 years). In comparison, differences in mean residence time due to N fertiliser treatment were small. However, tillage had generally very little effect on either the amounts of mineral N at sowing or soil organic C (and N) over the study period. While application of N fertiliser increased mineral N, it had very little effect on organic C over a 10-year period. Relatively rapid decomposition of straw and short mean residence time of straw N in a Vertisol is likely to have very little long-term effect on N immobilisation and organic C level in an annual cereal cropping system in a subtropical, semiarid environment. Thus, changing the tillage practice from CT to NT may not necessitate additional N requirement unless use is made of additional stored water in the soil or mineral N loss due to increased leaching is compensated for in N supply to crops.

Introduction

In no-tillage (NT) practice for cropping, straw is retained on the soil surface after the crop is harvested, whereas in conventional tillage (CT) systems, straw is incorporated into the plough layer, usually 0.1 to 0.15 m deep. Under NT practice, therefore, there is reduced contact of added straw with soil, with different temperature, moisture and aeration, and different rates of microbial activity (Doran and Smith 1987) and, hence, reduced straw decomposition and N turnover (Strong *et al*. 1987).

Incorporating straw into the ploughed layer of soil affects C and N dynamics (Strong *et al*. 1987; Dalal *et al*. 1991; Schomberg and Steiner 1999; Wang *et al*. 2004). For example, Strong *et al*. (1987) observed that soil mineral N decreased linearly at the rate of 5 kg N/t of straw addition to a Vertisol, and these effects were still evident 305 days after straw addition. However, the straw placement on the soil surface may have different effects on mineral N changes in soil as compared to straw incorporation. For C sequestration, Wang *et al*. (2004) found that straw retention increased soil organic C in the top 0.1-m depth only when accompanied by NT practice and fertiliser N application. There was no significant effect below 0.1-m depth. Thus, the 3-way interaction of tillage practice, straw retention and fertiliser on the amount of organic C in a Vertisol was demonstrated.

The objective of this study was to examine organic C and N dynamics in soil under NT practice compared with CT practice, which may necessitate differential N application for optimum crop production as well as for soil improvement. We compared the effects of NT and CT practices, with two rates of N fertiliser applied annually on: (i) the rates of mass loss and N changes during ^{15}N-labelled wheat straw decomposition; (ii) soil organic C, total N and presowing nitrate-N accumulation in the soil profile; and (iii) crop N yields over a 10-year period in a long-term field experiment.

Materials and methods

Field site

The study site was located at Warra (26°47′S, 150°53′E), Queensland, on a Vertisol (Typic Chromustert), with clay content of 55%, 0.7% organic C, 0.07% total N and pH 8.5 in the top 0.1-m depth. The properties of the soil profile are given by Dalal *et al*. (1995). Mean annual rainfall varied from 396 mm in 1986 to 767 mm in 1996, with a mean rainfall of 685 mm per

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annum. The mean maximum temperature in January was 27°C and mean minimum temperature was 12°C, with a mean annual temperature of 20.7°C.

Field treatments

The field experiment was conducted from 1987 to 1998. The experimental design and the treatments of this experiment are described in detail by Dalal *et al*. (1995). Briefly, four treatments (two tillage × two N rates) were established in a randomised block design with four replications in plots each 25 m long and 6.75 m wide. The tillage treatments were conventional tillage (CT) and no-tillage (NT) wheat cropping and the N fertiliser application rates were 0 and 75 kg N/ha.year, giving four treatments: (i) CT0N; (ii) CT75N; (iii) NT0N; and (iv) NT75N. The crop management of CT and NT wheat cropping without and with fertiliser N application treatments are described in detail by Strong *et al*. (1996*a*).

Straw collection

Ammonium nitrate depleted in ^{15}N (0.0118 atom% ^{15}N) was used to label wheat plants grown in the adjoining fertiliser N application experiment. The fertiliser was applied in four bands 0.5 m apart and placed at a depth of ~7 cm. The experiment consisted of four replicated blocks, with 3 m × 2.25 m plots. On 20 June 1989, ^{15}N-depleted fertiliser N was applied at 25 and 75 kg N/ha. Immediately, wheat (cv. Hartog) was sown in 0.25-m rows, on either side of the fertiliser band (Strong *et al*. 1996*b*). The wheat crop was harvested on 10 November 1989, and wheat straw was separated from grain and dried at 40°C for 48 h. For each fertiliser rate, wheat straw from all four replications was pooled together to obtain enough ^{15}N-depleted straw for the litterbag study. A subsample of straw was analysed for total N and ^{15}N concentration. Straw material from wheat produced on plots, to which 25 kg N/ha was applied, was used in the 0 kg N/ha.year fertiliser application treatments, and straw produced on plots, to which 75 kg N/ha was applied, was used in the 75 kg N/ha.year fertiliser application treatments for both NT and CT treatments. Straw, produced in the 25 and 75 kg N/ha treatments, respectively, contained 0.21% and 0.33% N and 0.256 atom% ^{15}N and 0.164 atom% ^{15}N.

Litterbag preparation, placement, recovery and analysis

Standard litterbags, supplied by the Tropical Soil Biology and Fertility program (Anderson and Ingram 1989), were used in this study. The bags were made of exuded polyvinyl with a 7-mm mesh size, 300 mm × 300 mm area and 25-mm depth. Wheat straw, cut into 200–250 mm size pieces of 10 g air-dry mass (7.856 g ash-free basis), was placed into each bag, and the ends were tied with plastic tie wire. On 1 December 1989, the bags were placed either on the soil surface in the NT treatment plots and secured to surface by wire or placed at 50–70 mm depth in the CT treatment and covered with soil after tillage and each subsequent tillage operations.

Litterbags were recovered after 0, 9, 18, 27, 45, 54, 72, 99, 151 and 180 weeks, placed into a plastic bag and transported to the laboratory. After removing the straw from the bag, the adhered soil was carefully removed, and the straw was dried at 40°C for 24 h and the straw air-dry weight was recorded. A subsample of straw was ignited at 550°C for 1 h to obtain ash-free weight.

Straw subsamples were ground and analysed for total N and ^{15}N using modification of the Kjeldahl method (Buresh *et al*. 1982), including nitrate-N by using reduced iron. The Kjeldahl digests were steam distilled and dried as $(NH_4)_2$ SO_4-H_3BO_3 salts, then analysed for total N and ^{15}N concentration on a Micromass MM 622 (VG Isotopes, Winsford, England) mass spectrometer.

Wheat grain and straw N yields

Wheat grain yields were measured from each plot (1.75 m × 20 m) by machine harvest and adjusted to 12% water content. Straw samples were obtained from 1-m long sections of two rows and were used for harvest index estimates (Strong *et al*. 1996*a*). Finely ground wheat grain and straw samples were analysed for N concentration in Kjeldahl digests using automated ammonium analysis (Crooke and Simpson 1971). Grain and straw N yields were calculated as the product of grain yield and grain N concentration and straw yield and straw N concentration, respectively.

Soil sampling and analysis

For nitrate-N measurements, soil was sampled to a depth of 1.5 m in May annually, before the crops were sown. Samples were divided into 0.1-m layers down to 0.3-m depth, and 0.3-m layers below 0.3-m depth, then stored at 4°C until analysis. Soil samples were dried at 35 ± 5°C in a forced draught oven and ground to <2 mm. Nitrate-N was extracted from 20 g soil in 100 mL of 2 mol/L KCl (Mulvaney 1996) and the extracts were analysed on autoanalyser (Best 1976). Bulk density measurements were made according to the procedure followed by Strong *et al*. (1996*b*) and were used to calculate the amounts of organic C, total N and NO_3-N at different depths in the soil profile.

Five soil samples were collected from each plot with a 50-mm diameter soil corer from the top 0.1-m layer each year and occasionally down to 0.3-m depth (Dalal *et al*. 1995). The samples were bulked, sealed in plastic bags, and stored at 4°C until analysis. After removing visible pieces of plant material, the soil was dried at 30°C, ground to <0.25 for determination of total N (Bremner 1996), including NO_3-N, by modified Kjeldahl method (Dalal *et al*. 1984), and organic C by Walkley–Black method adapted for spectrophotometric determination (Sims and Haby 1971). All soil results were reported on oven-dry weight basis.

The proportion of ^{15}N in decomposing straw remaining after different periods of incubation was calculated as follows:

$$^{15}\text{N straw } P_t = [(\%N_t \times M_t \times (^{15}N_t - ^{15}N_{ns})]/[(\%N_0 \times M_0 \times (^{15}N_0 - ^{15}N_{ns})] \quad (1)$$

where P_t is the proportion of ^{15}N straw remaining after incubation at time t (year); $\%N_t$ and $\%N_0$ are respective straw N concentrations (%) at time t and initially ($t = 0$); M_t and M_0 are respective masses of straw at time t and initially ($t = 0$); $^{15}N_t$ and $^{15}N_0$ are respective atom% excess ^{15}N straw at time t and initially ($t = 0$); and $^{15}N_{ns}$ is atom% ^{15}N of unfertilised straw (0.369 atom% ^{15}N).

Statistical analysis

Analysis of variance was performed to assess the effect of tillage and fertiliser practices on straw decomposition, grain and straw

N yield, and soil organic C, total N and NO_3-N in the soil profile each year, using balanced factorial design analysis (Snedecor and Cochran 1989). Time trends in straw decomposition were assessed using first-order decay regression analysis function in Sigmaplot 6.1 (Systat Inc.) as follows:

$$M_t = M_0 \, e^{-kt}, \quad (2)$$

or

$$M_t/M_0 = e^{-kt} \quad (3)$$

where M_t and M_0 are the masses of straw (g/bag) remaining after incubation at time t (years) and initially ($t = 0$), respectively; and k is the decomposition rate constant (g/g.year). Mean residence time (MRT) is the reciprocal of the decomposition rate, 1/k (years).

The relationship between the proportion of ^{15}N remaining in straw and straw N at different periods of incubation was assessed using linear regression function in Sigmaplot 6.1.

Results

The amount of straw remaining in soil decreased over the 3.45-year period (Table 1) under both tillage practices and N treatments. After 0.5 of a year (similar to the fallow period between successive wheat crops), >80% of the straw mass disappeared under the CT75N practice, while under the NT0N practice, <40% straw mass was lost from the soil. After 1 year, the straw mass remaining in the corresponding treatments was 14% and 71%, respectively.

Although there were significant effects of both tillage practice and N levels on straw decomposition, there was no significant tillage × N interaction or decomposition time × tillage × N interaction (Table 1). The straw decomposition followed exponential decay. The decay rate varied from 0.43 g/g.year under the NT0N practice, to 2.17 g/g.year under the CT75N practice. The straw MRTs for the respective treatments were 2.33 years and 0.46 years (Table 2). The mean MRTs for the CT and NT practices were 0.57 years and 2.04 years, respectively, while the mean MRTs for 0 and 75 kg N/ha.year fertiliser applications were 1.5 years and 1.1 years, respectively. Thus, the magnitude of MRT difference due to tillage was larger than that due to N fertiliser (Table 2).

The loss of straw N also followed first-order decay rates (Fig. 1). Although straw N loss rates under NT practice were slightly higher than the straw mass loss, those under CT practice were essentially similar. The MRT of straw N was ~0.57 years in soil under the CT practice and ~1.2 years under the NT practice. Thus, the MRT differences due to the N treatments (0 kg N/ha.year, 0.97 years *v.* 75 kg N/ha.year, 0.80 years) were much smaller than those due to the tillage practice (CT, 0.57 years *v.* NT, 1.2 years).

A proportion of the amount of straw N remaining was closely correlated with the straw ^{15}N remaining after different decomposition periods, although there was indication of ^{15}N enrichment of ~18% over the 3.45-year period (Fig. 2). This may be due to preferential mineralisation of the lighter ^{14}N-labelled organic N, as compared to ^{15}N-labelled organic N from straw materials, as the amount of N remaining in straw decreased with straw decomposition. However, there appears to be limited occurrence of N immobilisation, except for the CT0N treatment at the 9-week sampling only.

The amounts of nitrate-N in the soil profile at sowing under CT0N and NT0N varied from 35 kg/ha (6 months fallow) to 118 kg/ha (18 months fallow), with a similar mean value over all years (47 kg/ha for CT and 55 kg/ha for NT) (Table 3). Fertiliser N application increased the amount of nitrate-N for the next crop significantly in most years. However, there was no significant effect of tillage practice in 75 kg N/ha.year treatments (with mean values of 135 kg/ha for CT and 130 kg/ha for NT over the 10-year period) (Table 3).

Mean grain N yields over the 10 years of cropping showed a similar trend to that of nitrate-N in the soil profile at sowing (Fig. 3), but with much smaller errors. Again, tillage practice had no significant effect on grain N yield; in fact, the mean grain N yields were identical (33 kg/ha) for both tillage practices, without fertiliser N treatment, and very similar with application of 75 kg N/ha.year (57 and 58 kg/ha for CT and NT, respectively). Similar tillage and N treatment effects were observed for straw N yields; that is, no significant tillage effects but significant higher straw N yields with 75 kg N/ha.year fertiliser treatment (Fig. 3).

The mean amounts of C input from straw to the soil under NT and CT practices over a 10-year period were identical but

Table 1. Percentage of added straw remaining in soil under conventional tillage (CT) and no-tillage (NT) practices over the 3.45-year period

Period of decay (years)	CT practice 0 kg N/ha.year	CT practice 75 kg N/ha.year	NT practice 0 kg N/ha.year	NT practice 75 kg N/ha.year	l.s.d. ($P = 0.05$)[A] Tillage	l.s.d. N	l.s.d. Tillage × N
0	100.0	100.0	100.0	100.0	0	0	0
0.173	85.8	79.9	94.7	88.4	6.4	n.s.	n.s.
0.345	55.4	46.4	84.2	72.9	2.5	2.5	n.s.
0.518	27.1	19.2	62.6	55.3	8.7	n.s.	n.s.
0.862	31.5	19.4	71.7	54.0	6.6	6.6	n.s.
1.035	34.8	14.3	71.4	64.1	4.6	4.6	6.6
1.380	13.8	6.4	52.5	42.6	10.6	n.s.	n.s.
1.897	11.2	3.8	55.4	36.4	5.3	5.3	7.5
2.894	12.8	1.3	31.7	28.9	11.4	n.s.	n.s.
3.450	2.6	0.4	11.7	20.1	8.4	n.s.	n.s.

[A]Mean data l.s.d. values ($P = 0.05$) were: time (4.3), tillage (1.9), N (1.9), time × tillage (6.1), time × N (6.1), tillage × N (n.s.), time × tillage × N (n.s.). n.s., not significant.

Table 2. Straw decay rate and mean residence time in soil under CT and NT practices

Straw decay rate was calculated using the formula $Y = e^{-kt}$; where Y is the fraction after t (years) period of fractional decomposition (M_t/M_0); M_0 and M_t are the amounts of straw initially and after t years, respectively; k, rate of decay; MRT, mean residence time, given by 1/k; all R^2 values were significant ($P < 0.001$); values for k and MRT are presented as mean ± s.e.

Tillage	Fertiliser N (kg N/ha.year)	k (g/g.year)	MRT (years)	R^2
CT practice	0	1.46 ± 0.18	0.68 ± 0.08	0.92
	75	2.17 ± 0.19	0.46 ± 0.04	0.97
NT practice	0	0.43 ± 0.04	2.33 ± 0.24	0.91
	75	0.58 ± 0.06	1.74 ± 0.19	0.91

were 220–250 kg/ha higher with N fertiliser application in both tillage practices (Table 4). The C addition through straw retention was usually <2 t/ha in most years, with mean annual values of 1.0 t/ha without N application and 1.2 t/ha with 75 kg N/ha.year fertiliser application.

Amounts of soil organic C and total N were only slightly affected by tillage and N treatments and treatment differences were inconsistent over time (Table 5). For example, in 1994 the amount of organic C was highest in NT75N treatment, but in 1997 organic C was highest in CT75N treatment. Similarly, in 1989 soil total N was significantly higher in NT75N treatment than CT0N treatment, but in 1997 CT75N treatment contained a higher amount of total N than CT0N treatment. Similarly, no time trends with fertiliser application could be discerned, although without fertiliser application and irrespective of the tillage practice, both the amounts of organic C and total N showed decreasing trends.

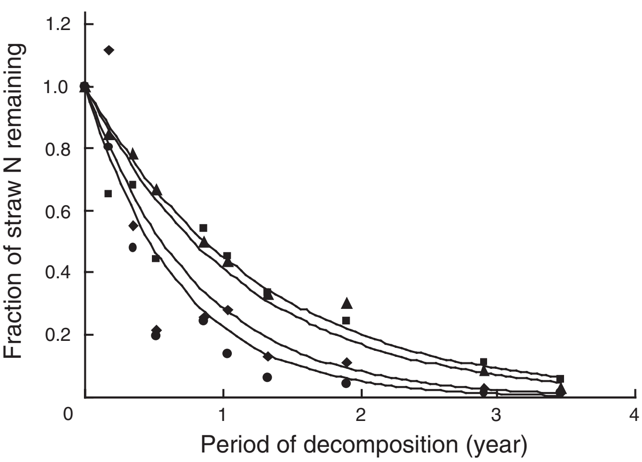

Fig. 1. Straw N disappearance over the 3.45-year period in soil under CT and NT practices with and without fertiliser N application in a Vertisol. CT0N and CT75N are conventional tillage practices with 0 and 75 kg N/ha.year, respectively. NT0N and NT75N are no-tillage practices with 0 and 75 kg N/ha.year, respectively. The regression lines are: CT0N (◆), $N_t/N_0 = e^{-1.52\,\text{year}}$, $R^2 = 0.86$ ($P < 0.01$); CT75N (●), $N_t/N_0 = e^{-2.08\,\text{year}}$, $R^2 = 0.96$ ($P < 0.01$); NT0N (▲), $N_t/N_0 = e^{-0.78\,\text{year}}$, $R^2 = 0.99$ ($P < 0.01$); NT75N (■), $N_t/N_0 = e^{-0.90\,\text{year}}$, $R^2 = 0.87$ ($P < 0.01$), where N_0 and N_t are the amounts of straw N initially and after t years.

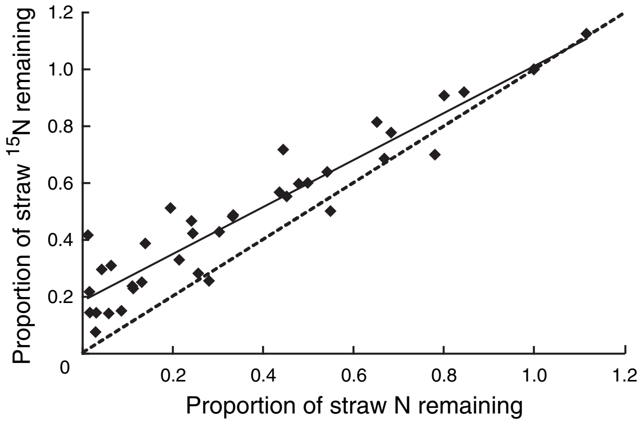

Fig. 2. Relationship between proportion of ^{15}N and amounts of straw N that remained over a 3.45-year period after straw was applied to soils under CT and NT practice with 0 or 75 kg/ha.year of applied N. The regression line (solid line) is $Y = 0.185 + 0.825X$; $R^2 = 0.92$, $P < 0.001$ (s.e. = 0.085). The 1 : 1 line is shown as a dashed line.

Discussion

Cereal stubble mass loss and N changes under NT and CT practices

In the semiarid region of northern Australia, cereal straw is retained principally to prevent soil erosion by overland water flow (Freebairn *et al*. 1986). Persistence of retained crop residues during summer, when heavy storm rainfall events can promote soil erosion, is essential for this practice to succeed. Thus, greater persistence of wheat straw with NT practice is reassuring, given the shift in recent years away from CT to NT practice. Greater persistence of straw with NT practice was presumably due to poor contact with the soil and microbial decomposers, as well as more rapid drying of straw retained on the soil surface (Andren *et al*. 1993).

Table 3. The amount of nitrate-N (kg N/ha) in the 0–1.2 m soil depth at sowing under different tillage and fertiliser N treatments over a 10-year period

No crop was grown in 1991 due to drought

Year	CT practice 0 kg N/ha.year	CT practice 75 kg N/ha.year	NT practice 0 kg N/ha.year	NT practice 75 kg N/ha.year	l.s.d. ($P = 0.05$)[A]
1989	35.4	51.1	40.4	45.9	n.s.
1990	37.9	62.6	46.9	57.2	17.6
1991	37.9	86.1	46.4	109.0	33.6
1992	88.7	179.3	117.5	148.0	46.6
1993	35.2	140.2	47.9	98.8	55.4
1994	46.6	143.4	44.4	138.1	60.3
1995	62.5	168.4	77.2	137.8	73.1
1996	40.4	222.9	40.7	209.7	58.9
1997	48	151.2	50.0	181.2	62.1
1998	38.3	146.0	43.7	170.3	47.3
Mean	47.1	135.1	55.5	129.6	46.8

[A] l.s.d. values are for comparing the fertiliser N effect; tillage effects were not significant for any given year. n.s., not significant.

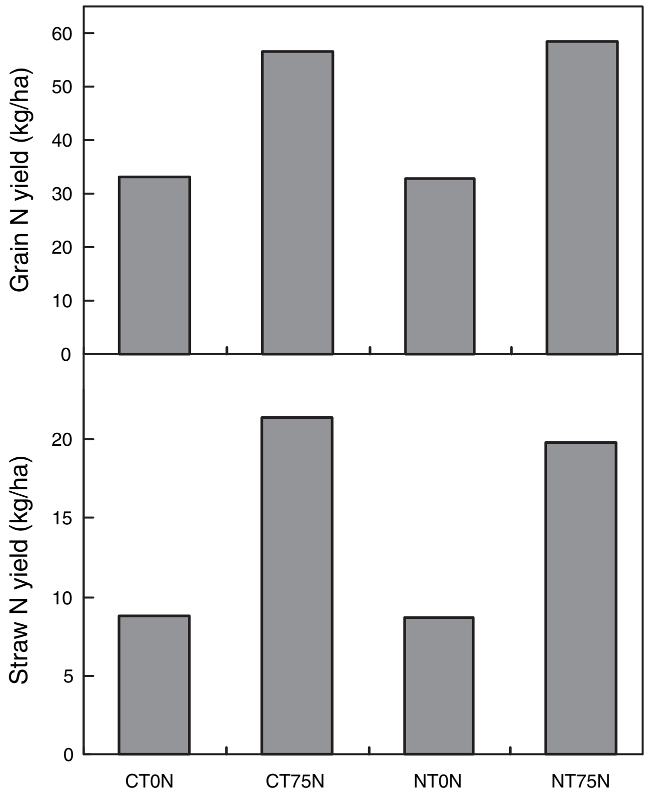

Fig. 3. Effects of tillage practices and N fertiliser application on grain N yield and straw N yield (mean values from 1989–98 period). CT0N and CT75N are CT practices with 0 and 75 kg N/ha.year, respectively. NT0N and NT75N are NT practices with 0 and 75 kg N/ha.year, respectively. Values of l.s.d. at $P = 0.05$ were 11.9 for grain N and 5.3 for straw N.

Greater persistence of cereal straw with NT practice might be expected to slow N release from straw and also reduce tie-up or immobilisation of soil available N supply. Rates of these opposing effects to the quantity of soil mineral N will influence the collective impact on plant available N supply. Apparently processes in soil under NT practice had no significant effect on soil available N supply by the time winter crops were sown, ~6 months after residues were retained (Table 3).

Table 4. The amount of wheat straw C (kg C/ha) produced under different tillage and fertiliser N treatments over a 10-year period
No crop was grown in 1991 due to drought

Year	CT practice		NT practice		l.s.d.
	0 kg N/ha.year	75 kg N/ha.year	0 kg N/ha.year	75 kg N/ha.year	($P = 0.05$)[A]
1989	1112	1505	1171	1596	148
1990	2001	2404	1994	2284	320
1991	0	0	0	0	–
1992	1982	1801	1932	2017	103
1993	816	1061	907	1127	100
1994	592	1039	600	960	177
1995	465	535	560	384	104
1996	1193	1434	788	1568	241
1997	1012	1256	1092	1526	403
1998	1030	1448	1013	1092	n.s.
Mean	1020	1248	1006	1255	197

[A] l.s.d. values are for comparing the fertiliser N effect; tillage effects were not significant for any given year. n.s., not significant.

However, following several successive cereal crops of high cereal biomass production, it is feasible that immobilisation of plant-available N may outweigh any possible benefit from straw N released. For example, incorporation of wheat straw at 0, 2.5, 5 and 7.5 t/ha to a Vertisol in a glasshouse experiment resulted in the immobilisation of 5–6 kg N/t straw added (Strong *et al*. 1987). This rate of N immobilisation would usually exceed the amount of total N in wheat straw produced in this region. Also, the amounts of wheat straw N of our crops were usually below (2.1–3.3 kg N/t) that of straw used in the Strong *et al*. (1987) study. Therefore, N supply to crops from straw retention and decomposition is likely to be small or negligible.

While NT practice decreased straw decomposition rates by almost 250%, application of N fertiliser (75 kg/ha.year)

Table 5. Amounts of organic C and total N in soil under different tillage and fertiliser N treatments in 1985, 1989, 1994 and 1997
n.s., not significant

Tillage	Fertiliser (kg N/ha.year)	Sampling time: Dec. 1985	Nov. 1989	Nov. 1994	Oct. 1997
	Soil organic carbon at 0–0.1 m depth (t/ha)				
CT practice	0	9.0	8.8	8.6	8.4
	75	9.0	9.2	8.6	9.1
NT practice	0	9.0	8.9	8.3	8.4
	75	9.4	8.8	9.5	8.5
l.s.d. ($P = 0.05$)		n.s.	n.s.	0.7	0.6
	Soil total nitrogen at 0–0.1 m depth (kg/ha)				
CT practice	0	873	866	860	733
	75	845	903	939	817
NT practice	0	855	860	830	804
	75	859	895	938	795
l.s.d. ($P = 0.05$)		n.s.	n.s.	90	72

caused only a modest increase in stubble decomposition (<30%) compared to the 0 kg/ha.year treatment. This was presumably due primarily to N cycling through microbial biomass within and in contact with the straw system, rather than with the soil mineral N (Strong *et al*. 1987). For example, Schomberg and Steiner (1999) found that N concentration of the wheat straw remaining in soil increased initially from 0.5% to 0.96% after 12 months of wheat straw decomposition in a clay loam in Texas, USA. We also observed increases in N concentration of the residual straw initially from 0.21% to 0.43%, and from 0.33% to 0.59%, in 0 and 75 N/ha.year treatments, respectively (data not shown), after 3.45 years of straw decomposition. The enrichment of ^{15}N in straw remaining over a period of 3.45 years (Fig. 2) also indicates, not only preferential utilisation of ^{14}N as compared to ^{15}N (Agren *et al*. 1996), but also N cycling within straw and/or straw associated microbial biomass during straw decomposition (Robinson 2001). Furthermore, wheat straw probably had limited interaction with applied fertiliser N, since the amounts of mineral N in soil and wheat N yields remained essentially unaffected (Table 3; Fig. 3).

Presowing nitrate-N and crop N yields under NT and CT practices

NT and CT practices had no significant effect on the amount of presowing NO_3-N in the soil profile in any year over a 10-year period (Table 3), with variable rainfall (317–607 mm) during the fallow (Dalal *et al*. 1998). A modest quantity of straw C retained following most wheat crops (average of all crops, <1.25 t/ha, Table 4) and modest production by most crops during this period under NT and CT practices may be responsible for showing no effects of tillage practices on plant-available N supply at sowing (Table 3) or on crop N recovery (Fig. 3).

In arid and semiarid regions, similar amounts of NO_3-N have been observed in the soil profile under both NT and CT practices (Fuentes *et al*. 2003). In fact, where crops under the NT practice have not been able to utilise antecedent soil water, especially under low in-crop rainfall conditions, higher amounts of NO_3-N were observed below the root zone in the soil under NT than CT practice (Turpin *et al*. 1998; Fuentes *et al*. 2003).

Repeated fertiliser N application resulted in higher amounts of NO_3-N than when fertiliser N was not applied to the soil (Table 3), although the straw mass loss and straw N decomposition rate were only slightly faster than without N treatment (Table 2; Fig. 1). This may have been due to limited interaction between straw and fertiliser N applied to the soil. Strong *et al*. (1987) found that, in a glasshouse experiment, the source of additional NO_3-N may have been soil microbial biomass N, organic or root N, but not the ^{15}N labelled straw N. Moreover, fertiliser residues also contributed to soil NO_3-N (Strong *et al*. 1996*b*), especially following drought (1991) and low grain N yields due to below-average growing season rainfalls from sowing to anthesis from 1993 to 1995 (Dalal *et al*. 1998).

The NT practice has been shown to benefit cereal cropping in this region (Radford *et al*. 1995), largely through improved water retention during the fallow period preceding the crop. Lower than average seasonal rainfall for most crops during this period would obviate this effect, resulting in similar cereal production for the two practices. It is, therefore, not surprising that similar quantity of grain and straw N was recovered for each tillage practice (Fig. 3), possibly due to overall rainfall shortfalls.

Organic C and N accretions in soil under NT and CT practices

Organic C concentrations in soil under different tillage practices were essentially similar, because of the similar rates of straw and root decomposition (Jalota *et al*. 2006). Also, straw C yields were similar in both NT and CT practices (Table 4) and only 200 kg C/ha.year more C were produced with fertiliser N than without N application. Similarly, root biomass yields were similar under all treatments (Dalal *et al*. 1995). Estimates of stubble C remaining after 10 years (calculated from Tables 2 and 4) were only 0.25 t/ha under CT and 1.4 t/ha under NT practice. Most of the stubble C would be in the light fraction without significantly increasing soil C in the top 0–0.1 m depth (Wang *et al*. 2004), although the top 0–0.025 m depth had higher organic C under the NT than CT practice (Dalal *et al*. 1995). Therefore, minimum or minor differences in soil organic C concentrations within the surface 0.1-m soil layer were expected in this Vertisol (Dalal *et al*. 1991, 1995). Since NT practice leads to soil organic C stratification, the treatment effects in the top soil layers are likely to be found significant if soil is sampled at smaller depth intervals, rather than bulk sampling of the top 0.1-m depths (Dalal *et al*. 1995).

Conclusion

The NT practice decreased straw decomposition rates, due to differences in placement and soil contact with straw as compared to the CT practice in this study. However, there was no tillage effect on the amounts of nitrate-N production, and organic C and N in this Vertisol soil over a 10-year period. Consequently, mean grain N and straw N yields were similar under both NT and CT practices, and showed similar responses to fertiliser N application. Therefore, in this semiarid and subtropical environment, changing farming practices from CT to NT did not necessitate increase in N application for soil improvement or crop production. In field situations, where NT practice may have higher plant available water or greater N leaching losses than CT practice, the crop production and profitability may be increased in the NT practice from additional fertiliser N application, by matching plant available water to nitrate-N in the profile at sowing (Dalal *et al*. 1997).

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