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Suppression of wheat early growth in standing stubble

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Abstract. Early growth and development are often lower when wheat is sown into standing stubble. A study was conducted to determine whether this difference in early growth could be explained by the effects of stubble on soil temperature in the vicinity of the young plant. The roles of nitrogen nutrition and soil strength were also assessed. Three crops were monitored (1990–1992), with the wheat being sown into either standing wheat stubble after a no-till fallow (NT), or into no-tilled plots from which the stubble had been removed by burning (NB). Measurements were made of wheat growth and development, soil and plant N, soil temperature and penetration resistance. The site was on a black earth near Warialda in the northern wheatbelt of New South Wales, Australia. In 1992 wheat was also grown under simulated stubble to isolate the shading and soil temperature effects of stubble from other factors. A significant (P<0.05) relationship was found between average soil temperature and above ground dry matter (DM) at 65 days after sowing (DAS) but not at 107 DAS. This relationship accounted for differences in DM production at 65 DAS between NT and NB treatments in 1991 and 1992, but not in 1990. In that year the lower DM production in NT plots was associated with poorer N nutrition, and possibly disease. Laboratory incubations indicate that immobilisation of N as stubble decomposed could have contributed to this. Burning stubble produced no immediate increase in soil N availability, so that it is unlikely that N contained in stubble contributed to the difference. Soil strength differences between treatments and phytotoxic effects are unlikely to have contributed to growth differences in this soil.

Key words: Soil temperature – *Triticum aestivum*– Stubble retention – Nitrogen – Early growth

Introduction

In Australia, sowing wheat directly into standing stubble often shows poorer early growth than wheat sown into soil prepared by conventional cultivation practices, which leave less above-ground plant residue [5 , 7, 20, 24]. Kirkegaard [16] reviewed the effects of stubble retention and tillage on wheat yields, drawing on data from 33 medium- and long-term agronomic trials, spread over all the major wheat growing areas of Australia. Tillage had little overall effect on yield in any region, but retention of stubble caused a decline in yield in all regions.

There are several differences between the two cropping practices which could account for an early growth lag under standing stubble.

1. Less soil disturbance with direct drilling may result in higher soil strength and consequent restriction of root growth [5, 7].

2. Some incorporation of stubble occurs when sowing into standing stubble and this may lead to phytotoxic effects [19], or lower soil nitrate concentrations [28]. Because its high C/N ratio encourages net immobilisation of soil N, decomposing wheat stubble has long been known to have the potential to lower soil N availability.

3. Chan et al. [5, 6] found evidence that soil micro-organisms were adversely affecting growth of direct drilled wheat.

4. Aston and Fischer [3] showed that the soil temperature regime for wheat grown under standing stubble differed from that for wheat grown after conventional cultivation, and suggested that temperature could be at least partly responsible for the observed growth lag. Similarly, Kirkegaard et al. [17] observed lower daytime temperatures when stubble was retained and suggested that this might be partly responsible for the reduced growth. In North America, microclimate effects of stubble have also been related to differences in wheat growth. In an experiment with winter wheat in Oregon, Wilkins et al. [30] found that standing stubble decreased soil temperature and photosynthetically active radiation within the canopy, as well as reducing main-stem leaf development, tillering, dry matter at late tillering, and stem height at harvest. Cutforth and McConkey [8] found that for spring wheat grown in Saskatchewan, sowing into tall stubble increased dry matter and grain yield, and altered the microclimate near the soil surface, lowering soil temperature, windspeed and incoming solar radiation, and increasing reflected solar radiation. A feature of all these experiments is that, while they report correlations between the microclimate produced by stubble and wheat growth or development, it is difficult to establish the extent to which microclimate is actually the cause of the plant effects. There is always the possibility that some other factors associated with stubble retention are having a major effect. The present experiment sought to address this issue.

Standing stubble affects soil temperature close to the surface because it affects the energy balance at the soil surface [4]. Part of the solar radiation is reflected or absorbed by the straw, so that less reaches the soil. Turbulent transfer of heat between the soil surface and the atmosphere is inhibited by a stubble mulch, so that the soil reacts more slowly to changes in atmospheric temperature. The evaporation rate at a given surface soil moisture content is lower under stubble mulch due to less incoming radiation and slower latent heat flux. Differences in soil temperature caused by the presence of stubble might affect plant growth directly. Other factors, associated with solar radiation, might also be involved, such as shading effects from standing stubble on photosynthetic radiation.

Many aspects of wheat growth and development are influenced by temperature. For example, Addae and Pearson [1] showed that the processes between sowing and emergence of wheat (imbibition, germination, coleoptile elongation, root elongation and shoot elongation) were all dependent on temperature. The rate of many growth and development processes is a linear function of temperature. This results in the extent of growth or development being linearly related to the product of time and temperature above a base temperature (referred to as accumulated temperature or thermal time). For example, leaf appearance can be related to accumulated temperature by means of a linear [10, 14] or bi-linear function [13]. Leaf extension is also linearly related to accumulated temperature [10, 14], as is the duration of leaf expansion [10]. The influence of other factors on the development rate of wheat may be due in part to their effect on plant temperature. Examples are the effects of water stress [2] and nitrogen status [26]. The tendency to linear relationships between temperature and the rate of plant growth or development means that average temperatures are likely to be good predictors of the latter, so long as the minimum temperature remains above the base temperature. The effect of temperature depends on the where in the plant it acts. During the early stages of the growth of an emerged monocotyledon, before stem elongation, leaf expansion occurs at the shoot apex located just below the soil surface, and it has been shown that the rate of leaf growth is particularly sensitive to temperature changes at this site [27].

In this paper observations are reported of a lag in early wheat growth associated with stubble retention during two years (1990 and 1991) at a site near Warialda in northern New South Wales (NSW). It was hypothesised that soil temperature difference between the stubble-burned and stubble-retained plots was a cause of the differences in growth. The hypothesis was tested in the 1992 season by growing wheat in "artificial stubble", which was designed to mimic the effect of stubble on the energy balance at the soil surface without introducing other potentially deleterious effects of stubble such as phytotoxicity, nitrate depression and microbial effects. The relationship between soil temperature and early growth through the artificial stubble was used to assess the contribution that microclimatic effects had made to the early growth lag in wheat crops grown at the same site from 1990 to 1992.

Materials and Methods

Experimental work was carried out at the Douglas McMaster Research Station near Warialda, New South Wales (150° 36' E, 29° 18' S), on a black earth (Self-mulching Black Vertosol: [13]), which is a soil type widely used for cropping in northern NSW and southern Queensland. Rainfall at Warialda averages 685 mm annually and is summer dominant. The warmest month is January (mean daily maximum=34 °C, minimum=16 °C), and the coolest is July (mean daily maximum=18 °C, minimum=0 °C). Two stubble management treatments were compared: no-till with 30-cm-high standing stubble retained (NT) and no-till with stubble burned (NB). Due to factors beyond the researchers' control, some aspects of the experimental design varied between years.

1990 season
In 1990, measurements were made on part of a tillage trial run by NSW Department of Agriculture [9], the 10 by 40 m plots used having been sown annually to wheat since 1981. Nitrogen (40 kg N/ha) as ammonium nitrate was spread over the site on 29 March. Part of six NT plots was burned on 8 June to make six NB plots (each 3.3 by 10 m), and the site was sown on the same day with wheat (variety Janz) at 45 kg/ha with 12.6 kg N/ha as diammonium phosphate applied. Plant establishment was measured at 30 days after sowing (DAS) from 4 by 0.5 m of row/plot. Plant samples were taken for development scoring (four plants/plot) at 56, 77 and 109 DAS. Harvests were made for above-ground dry matter (DM) determination (2 by 0.5 row m/plot) on the same days, and plant N was determined on the samples from 56 DAS. Soil cores (0 to 100 mm depth, two cores/plot) were taken at 30 DAS for inorganic N analysis. Soil temperature was measured in two plots per stubble treatment from 12 DAS at 90 min intervals by means of thermocouples inserted at 10, 50, 100 and 200 mm depth (two replicates at each depth) and recorded on a datalogger (manufactured by the Electronic Services Unit, University of New England).

1991 season
In January 1991 a trial was set up adjacent to the 1990 experimental site comprising three blocks of four stubble management treatments (10 by 20 m plots), of which two are relevant to this paper, namely no-till fallow with stubble retained and no-till fallow with stubble burned on 29 January. The site was fertilised with urea at 11.5 kg N/ha and sown with wheat (Hartog) at 45 kg/ha, with 10 kg N/ha as diammonium phosphate with seed on 19 June. Plant establishment was measured at 28 DAS in 6 by 1 m row/plot. Samples for plant development scoring (four plants/plot) and above ground DM (4 by 0.5 m row/plot) were taken at 58, 92 and 120 DAS. The DM samples from 58 DAS were analysed for plant N. Soil cores (0-100 mm, three cores/plot) were taken for inorganic N analysis at 58 DAS. Soil temperatures were measured on one block at depths of 5, 25, 75 and 150 mm, with two replicate thermocouples/plot.

1992 season
An experiment was set up in which artificial stubble was used to create a soil surface microclimate similar to that for real stubble but without the other potential effects of stubble on wheat growth such as nitrogen immobilisation, disease and phytotoxicity. The experiment was established within an NB plot and adjacent NT plot from the long-term NSW Department of Agriculture trial, which had been fallowed since November 1990. The experimental units were 2 by 1.5 m microplots. On the NB plot three treatments - zero stubble

and artificial stubble at low (S1) and high (S2) densities - were randomised in three blocks. On the NT plot, three microplots of the same size were selected at random.

Artificial standing stubble was simulated by vertical pieces of shadecloth (each 250 by 250 mm), using low density shadecloth for S1 and high for S2. Four pieces of shadecloth, stiffened with fencing wire, were erected with 250 mm gaps along the length of a horizontal 2 m wooden stake. The wooden stakes and shadecloth each simulated a 2 m row of standing stubble, and were pegged to the ground at 300 mm row spacing. Gaps in adjacent rows were offset. Fallen stubble was simulated by strips of 15-mm-wide plastic packing tape, loosely arranged over the soil surface. Each 1.5 by 2 m plot thus comprised six rows of artificial stubble, with the new crop growing down the centre of the 300 mm space between each row.

The treatments were applied at 12 DAS, before emergence. Two thermocouples per plot, wired in parallel to give an average temperature, were installed close to the centre of the plot at 10 mm depth. They were held in place by slotting the wire through a horizontal hole in a 20 by 10 by 150 mm Perspex stake which had been driven into the ground. Temperature was measured every 10 min, and average, maximum and minimum temperatures were logged for each day using a Campbell Scientific 21X datalogger. In order to prevent soil compaction during installation of the artificial stubble and thermocouples, work was carried out from a scaffold held above the plot. All plots were treated with Nitram (20 kg N/ha) on 23 June, 28 DAS. Plant establishment was measured at 27 DAS (2 by 1 m row/plot). At 65 and 107 DAS, above-ground plant parts were harvested for DM (2 by 0.5 m per plot) and samples were taken for plant development scoring (four plants/plot). Plant N was measured on the 65 DAS DM samples. Cores (0 to 100 mm, two cores/plot) were taken at 65 and 107 DAS for determining inorganic N and mass water content. Penetration resistance was measured at 65 DAS (three penetrations to 300 mm depth per plot), using a Rimik hand-operated cone penetrometer.

Analyses
In all years, plant development was measured using the scoring system which was most sensitive at the crop's current development stage. When the plants were young (up to and shortly after ear initiation) a scoring system based on dissection and examination of the shoot apex was used. Later the Feekes scale [18] or the Zadoks scale [22] was used.

Inorganic N was determined on soil samples extracted with 2M KCl either in the field (1991 and 1992) or after air drying (1990). Analysis for nitrate and ammonium was by autoanalyser. Plant N was determined by dry combustion using a Carlo Erba CNS analyser.

Effects of stubble on measured parameters were explored by means of analysis of variance. Where treatments were found to have significant effects, Duncan's multiple range test was used to estimate least significant differences.

Results and Discussion

Rainfall during the study period

Table 1 Rainfall (mm) during the study period in comparison to long-term means

	Dec. - May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Jun. - Nov.	Annual
Dec 1989 - Nov 1990	413	38	45	30	16	31	6	166	579
Dec 1990 - Nov 1991	391	26	52	0	2	13	40	134	525
Dec 1991 - Nov 1992	283	39	14	60	2	0	0	116	399
Long-term mean	385	46	46	40	44	58	66	299	685

Data collected at study site are compared to long-term means from the Warialda Post Office

Rainfall during the study period tended to be lower than average, especially during the last months of the growing seasons (Table 1). 1992 was a particularly dry year. The fallows prior to the 1990 and 1991 crops had close to average rainfall.

Effect of stubble on plant growth and development

There was no significant effect of stubble retention on establishment of wheat during 1990 and 1991 (Table 2). During both years and for all samplings the average score for plant development was consistently lower when stubble was retained, although this was only statistically significant in 1990 at 109 days and in 1991 at 58 days.

Table 2 Effect of stubble retention on plant establishment and development

Season	Days after sowing	No-till, stubble burned	No-till, stubble retained	Significance of difference
		Plant establishment (plants/m^2)		
1990	30	111	113	n.s.
1991	28	158	135	n.s.
		Plant development score		
1990	56	3.4	2.9[a]	n.s.
1990	77	6.5	5.6[a]	n.s.
1990	109	8.8	7.7[b]	$P<0.001$
1991	58	5.4	4.6[a]	$P<0.050$
1991	92	33.3	32.9[c]	n.s.
1991	120	75.0	72.5[c]	n.s. (P=0.07)

n.s. not significant

[a]Based on examination of shoot apex, double ridge stage = 4

[b]Feekes scale [18]

[c]Zadoks scale [22]

Above-ground DM production also tended to be lower where wheat was sown into stubble (Table 3). In 1990 at 56 and 109 DAS and in 1991 at 58 and 92 DAS DM was significantly lower when stubble was retained.

Table 3 Effect of stubble retention on above- ground dry matter (kg/ha)

Season	Days after sowing	No-till, stubble burned	No-till, stubble retained	Significance of difference
1990	56	230	140	$P<0.05$
1990	77	1070	730	n.s.
1990	109	4520	3120	$P<0.05$
1991	58	300	190	P<0.01
1991	92	3330	2320	P<0.01
1991	120	5720	5870	n.s.

n.s. not significant

Effect of stubble on plant and soil nitrogen

In 1990 at 30 DAS there was significantly ($P<0.05$) less inorganic nitrogen in the top 100 mm of soil where stubble had been retained (Table 4). At the same time plant nitrogen concentration was lower. Because the concentration of N in wheat plants declines as the plant develops [25], and because the plants in stubble retained treatments were generally less developed than with stubble burning, the difference in plant N cannot be explained by differences in plant development. Coupled with the difference in soil inorganic N, the difference in plant N suggests poorer N nutrition in the stubble retained plots.

In 1991 there was no evidence of differences in N nutrition between treatments. At 58 DAS there were no significant differences for either soil inorganic N to 100 mm or N concentration of above-ground DM (Table 4).

Table 4 Above-ground plant N and soil inorganic N (0 to 100 mm)

Season	Days after sowing	No-till, stubble burned	No-till, stubble retained	Significance of difference
		Soil inorganic N (mg/kg)		
1990	30	20.0	17.2	$P<0.05$
1991	58	13.7	18.7	n.s.
		Plant N (g/kg)		
1990	56	45	40	$P<0.05$
1991	58	37	39	n.s.

n.s. not significant

Effect of stubble on soil temperature

In 1990 the mean soil temperature from when sensors were installed at 12 DAS until harvest at 158 days (averaged over depths from 10 to 200 mm) was lower for NT than for NB by 0.6 °C (Table 5). However, the difference was not significant during the early part of the growth period, which for present purposes was taken as 12 to 64 DAS. This interval was chosen as it enabled comparison with data from the artificial stubble experiment in 1992, and also included most of the time for which the shoot apex remained below the soil surface.

During 1991 soil temperature differences between stubble treatments were larger and were significantly different when averaged over depths (5 to 150 mm) for both the period from installation at 7 DAS to harvest at 152 DAS and for 12 to 64 DAS (Table 5).

Table 5 Average soil temperatures 1990 and 1991 (°C)

Days after sowing	No-till, stubble burned	No-till, stubble retained	Significance of difference
	1990[a]		
12-158	14.2	13.6	$P<0.05$
12-64	10.2	10.0	n.s.
	1991[b]		
7-152	15.2	14.2	$P<0.001$
12-64	10.6	9.8	$P<0.001$

n.s. not significant

[a]Averaged over depths 10, 50, 100 and 200 mm

[b]Averaged over depths 5, 25, 75 and 150 mm

Fig. 1 shows the relationship between average soil temperature and depth for 12 to 64 DAS in 1990 and 1991.

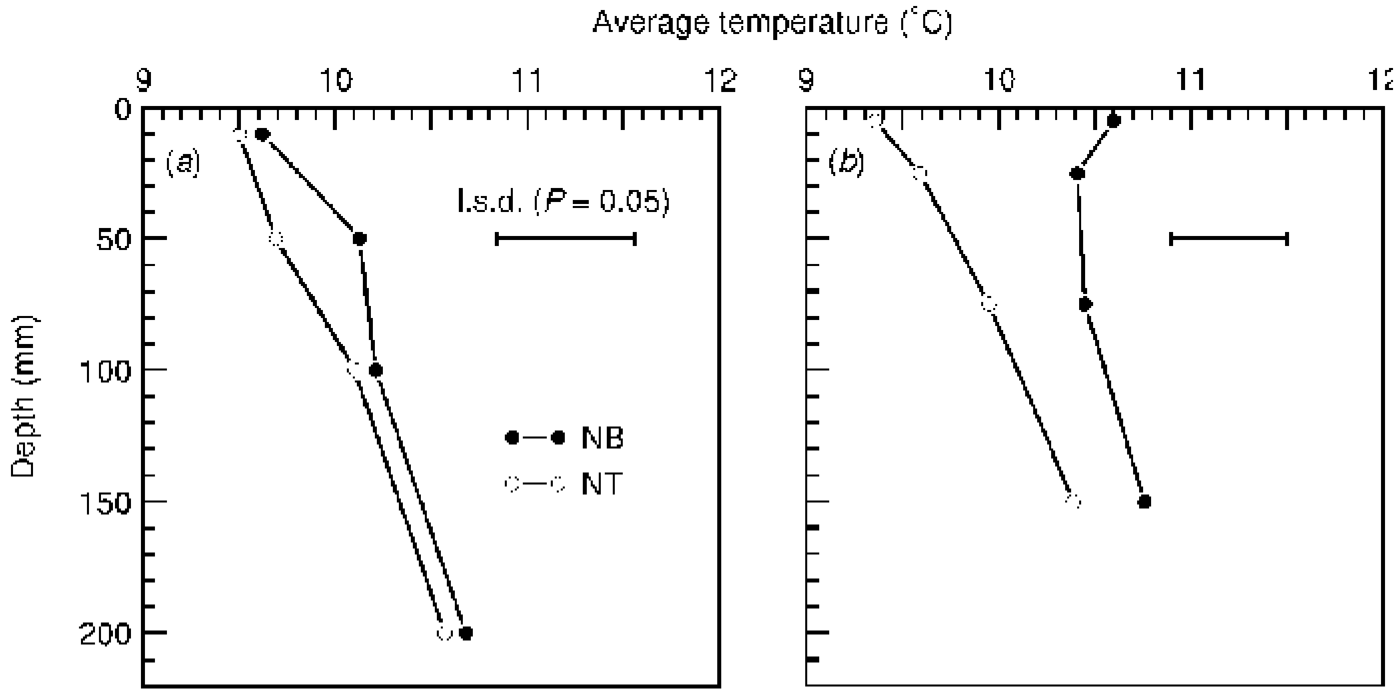

Fig. 1 Average soil temperatures from 12 to 64 days after sowing in *(a)* 1990 and *(b)* 1991

Simulated stubble experiment 1992

The simulated stubble did not affect establishment, nor was there any effect of real stubble on establishment (Table 6). Similarly plant development scores showed no significant differences between stubble treatments (real or simulated) at either 64 or 107 DAS. The real stubble surface density was low after sowing, estimated at 500 kg/ha, because the 18 month fallow since the previous wheat crop had permitted considerable decomposition. There were no significant differences in soil inorganic N to 100 mm at 65 DAS or 107 DAS. There were, however, small but significant ($P<0.05$) differences in plant N, with the artificial stubble treatments having slightly higher N concentrations than NT and NB treatments. The reason for this is not known. There were no significant differences in mass water content to 100 mm at either 65 DAS or 107 DAS. At 65 DAS there were no significant differences between treatments in penetration resistance at any depth to 300 mm.

Table 6 Effects of real and artificial stubble 1992

	No-till, stubble burned	No-till, stubble retained	Simulated stubble, low intensity	Simulated stubble, high intensity
	28 DAS			
Establishment (plants/m^2)	94	99	91	99
	65 DAS			
Plant development score[a]	3.2	3.1	3.3	2.8
Above ground plant N (g/kg)	44.0a	44.3a	46.4b	46.4b
Soil inorganic N, 0–100 mm (mg/kg)	32	17	30	13
Soil water content, 0– 100 mm (kg/kg)	0.35	0.36	0.36	0.38
Penetration resistance, 0–100 mm (MPa)	0.51	0.41	0.36	0.50
Penetration resistance, 100–200 mm (MPa)	0.93	0.87	0.96	0.88
Penetration resistance, 200–300 mm (MPa)	0.88	0.92	0.93	0.89
	107 DAS			
Plant development score[b]	32.5	32.6	32.6	32.9
Soil inorganic N, 0– 100 mm (mg/kg)	2.2	2.0	2.1	2.6
Soil water content, 0– 100 mm (kg/kg)	0.37	0.38	0.35	0.36

The only significant differences, between above-ground plant N at 65 DAS, are indicated by different letters (P<0.05)

[a]Based on examination of shoot apex, double ridge stage = 4

[b]Zadoks scale [22]

Relationships between above-ground DM production and soil temperature under the bare soil or simulated stubble were explored using linear regression analysis (Table 7). No relationships were found between average daily maximum or minimum temperature and DM. Dry matter at 65 DAS was, however, significantly related to average soil temperature (10 mm depth) from 12 to 64 DAS (P<0.05). This relationship did not carry through to 107 DAS.

Table 7 Relationships between temperature *(x)* and DM *(y)* (kg/ha) from artificial stubble experiment derived from linear regression analysis for the equation $y=a+bx$ (n=9)

x (°C)	a	b	r^2	*P*
DM at 65 DAS				
Average temperature 12–64 DAS	- 1692	220	0.49	<0.05
Daily maximum temperature, averaged 12–64 DAS	- 168	36	0.19	n.s.
Daily minimum temperature, averaged 12–64 DAS	56	70	0.04	n.s.
DM at 107 DAS				
Average temperature 12–106 DAS	- 5379	872	0.13	n.s.
Daily maximum temperature, averaged 12–106 DAS	111	216	0.08	n.s.
Daily minimum temperature, averaged 12–106 DAS	1470	322	0.02	n.s.

n.s. not significant
DAS, days after sowing

Discussion of temperature effects

In Fig. 1, the tendency of average temperature to increase with depth implies an average upward heat flux, which is consistent with the slow outward movement of heat stored deeper in the soil during the previous summer. The greater difference in average temperature between stubble treatments in 1991 than in 1990 is not attributable to differences in quantity of stubble as in 1990 the surface density of stubble was 2100 kg/ha compared to 1500 kg/ha in 1991. A more likely explanation is the drier conditions prevailing during 1991. Wet conditions tend to minimise differences in temperature due to surface residues [4]. In 1990, rain was recorded on 15 days between 0 and 65 DAS yielding a total of 90 mm, whereas in 1991 rain fell on only 4 days of the corresponding period, yielding 52 mm.

The relationship between average soil temperature at 10 mm depth and DM at 65 DAS implies that DM increased by 220 kg/ha °C (Table 7). In order to determine whether a temperature response of this order could account for differences between NB and NT treatments, DM contents at 65 DAS were estimated for 1990 and 1991 crops assuming exponential growth between the samples taken before and after 65 DAS (Table 8). Similarly, as soil temperatures in 1991 were measured at 5 and 25 mm (Fig. 1), the average temperature at 10 mm was estimated by linear interpolation. In 1990 the small measured temperature difference (0.1 °C) would not account for the estimated DM difference of 160 kg/ha. However, in 1991 the estimated DM difference was 167 kg/ha, which is of the same order as that predicted by the temperature difference (1.1×220=240 kg/ha). In 1992 the measured difference in soil temperatures of 0.34 °C would give a predicted DM difference of 75 kg/ha, which is similar to the measured difference of 53 kg/ha.

Table 8 Estimated average soil temperature 12 to 64 days after sowing at 10 mm depth and estimated above-ground DM at 65 days after sowing in 1990 and 1991

	1990		1991		1992	
	DM (kg/ha)	Soil temperature (°C)	DM (kg/ha)	Soil temperature (°C)	DM (kg/ha)	Soil temperature (°C)
No-till, stubble burned	444	9.62	488	10.55	592	10.31
No-till, stubble retained	284	9.50	321	9.42	539	9.97
Difference	160	0.12	167	1.13	53	0.34

In 1991 the difference in DM had disappeared at 120 DAS (Table 3) as the NT treatment caught up with the NB treatment. This is also consistent with the results from the artificial stubble experiment which showed that the relationship between DM and average soil temperature had disappeared at 107 DAS.

Stubble may also affect plant growth by shading and this is confounded with soil temperature effects, as increasing quantities of stubble are expected to produce increased shading and decreased average soil temperatures. No attempt has been made here to separate these factors.

Although low temperature lengthens the time to emergence of wheat, Addae and Pearson [1] found that the proportion of sown wheat seed that eventually emerges is unaffected by temperature from 8 to 25 °C. This is consistent with the establishment data for 1990 and 1991.

After the shoot apex leaves the soil during stem elongation, growth and development rates would be expected to become more closely related to air temperature than soil temperature. Close relationship between wheat leaf extension rate and air temperature has been observed experimentally [11]. Thus one would expect that the temperature effects of stubble would diminish with time. The observed disappearance of the relationship between DM and soil temperature between 65 and 107 DAS in the artificial stubble experiment is consistent with this and further suggests that there was a catching-up process.

Discussion of nitrogen nutrition

The observed differences in plant N and soil inorganic N between stubble treatments in 1990 are evidence of poorer N nutrition where stubble was retained. This may be due to a number of causes.

The standing stubble contained a pool of N estimated as 15 kg/ha which, had it been converted to inorganic N and deposited on the soil surface when burned, would have significantly increased the pool of available soil N. However, unpublished data from when stubble was burned at Warialda at the start of the 1991 fallow suggests that very little of the stubble N is deposited in the soil as inorganic N or as readily mineralisable N. No significant difference was found in nitrate, ammonium or hot KCl extractable ammonium in soil after burning stubble containing 15 kg N/ha. The sensitivities of the determinations were such that an addition of 0.8 kg inorganic N/ha or 0.6 kg hot KCl extractable NH_4-N/ha would have produced differences significant at *P*=0.05. This is consistent with the observation of Norman and Wetselaar [21] that burning of native pasture resulted in the volatilisation loss of more than 90% of biomass N.

Laboratory incubations (Hickman and Lockwood, unpublished data) of Warialda soil containing wheat straw suggested that there would be a difference between the NB and NT treatments in 1990 of about 2.5 mg inorganic N/kg to 100 mm depth due to immobilisation. The observed difference at 30 DAS was 2.8 mg N/kg, but this figure would also have been affected by any difference in plant uptake between the treatments. The data suggest that immobilisation could have had a significant effect on N nutrition during early crop growth. The adverse effect of stubble-induced immobilisation of N would be exacerbated by the likely proximity of the straw and the seedling due to the straw being incorporated by the seed drill.

Other factors affecting wheat growth

It is unlikely that differences in soil strength between NT and NB treatments were involved in producing differences in crop growth. Firstly, there was no difference in soil disturbance or trafficking between the stubble treatments. Secondly, soil moisture contents were similar or higher under NT than NB, which would tend to reduce soil strength. Thirdly, cone penetrometer measurements at 65 DAS in 1992 showed no significant differences between NB and NT treatments and penetration resistances were all relatively low (<1 MPa) (Table 6). Fourthly, measurements of cone penetrometer resistance at the Warialda trial in 1987 and 1988 showed that penetration resistances between 100 and 300 mm were not significantly higher under NT at any given water content than for plots which had a history of stubble incorporation during fallow or stubble burning+cultivation during fallow [12]. This suggests that the strength of the black earth at Warialda is relatively insensitive to tillage and stubble management, in contrast to soils such as the red earths investigated by Cornish and Lymbery [7], which can exhibit high soil strengths unless disturbed by cultivation.

Lovett and Jessop [19] found that 3000 kg/ha unweathered wheat straw spread over the surface at sowing lowered wheat emergence by 60%, and linked this to phytotoxicity. In the present experiments, however, the straw had been weathered for at least 6 months before the next crop was sown, and no effect of stubble on establishment was seen (Tables 2 and Table 6), suggesting that phytotoxic effects of stubble were not of major importance.

Plant disease was not monitored in this experiment, and so its contribution to early growth differences between the two treatments cannot be assessed directly. However, in 1991 and 1992, soil temperature alone was sufficient to account for dry matter differences at 65 DAS, so any contribution from disease must have been small. In 1990, while there was evidence of a difference in N nutrition between the treatments, the influence of N on growth could not be quantified. It is therefore possible that in that year disease also made a significant contribution. Yellow spot (caused by *Pyrenophora tritici-repentis*) is a common foliar disease of wheat in northern NSW and Queensland [23]. Crown rot (caused by *Fusarium graminearum* Group 1) and common root rot (caused by *Bipolaris sorokiniana*) are the major soil-borne diseases [29]. All can be carried over from crop to crop on wheat stubble, and so tend to be more severe when stubble is retained.

Conclusions

The artificial stubble experiment in 1992 indicated that soil temperature and possibly associated shading effects induced by artificial stubble can suppress the early growth of wheat. The relationship between average temperature depression from 12 to 64 DAS and DM difference at 65 DAS was sufficient to account for the large difference of DM production between NB and NT treatments in 1991, and the small difference in 1992. In 1990 the temperature/shading effect was not sufficient to account for the difference, but in that year no-till stubble retained plots showed evidence of poor N nutrition. Depression of soil inorganic N was similar to that produced in the laboratory by immobilisation induced by wheat straw. Plant disease, which was not assessed, could also have contributed in 1990. The evidence indicates that soil strength differences were not involved in creating differences in early growth in this soil, and there is no evidence that phytotoxicity was of major significance.

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References

[1] Addae P.C., Pearson C.J. (1992) Thermal requirements for germination and seedling growth of wheat. Aust J Agric Res **43:**585-594

[2] Angus J.F., Moncur M.W. (1977) Water stress and phenology in wheat. Aust J Agric Res **28:**177-181

[3] Aston A.R., Fischer R.A. (1986) The effect of conventional cultivation, direct drilling and crop residues on soil temperatures during the early growth of wheat at Murrumbateman, New South Wales. Aust J Soil Res **24:**49-60

[4] Bristow K.L. (1988) The role of mulch and its architecture in modifying soil temperature. Aust J Soil Res **26:**269-280

[5] Chan K.Y., Mead J.A., Roberts W.P. (1987) Poor early growth of wheat under direct drilling. Aust J Agric Res **38:**791-800

[6] Chan K.Y., Mead J.A., Roberts W.P., Wong P.T.W. (1989) The effect of soil compaction and fumigation on poor early growth of wheat under direct drilling. Aust J Agric Res **42:**221-228

[7] Cornish P.S., Lymbery J.R. (1987) Reduced early growth of direct drilled wheat in southern New South Wales: causes and consequences. Aust J Exp Agric **27:**869-880

[8] Cutforth H.W., McConkey B.G. (1997) Stubble height effects on microclimate, yield and water use efficiency of spring wheat grown in a semiarid climate on the Canadian prairies. Can J Plant Sci **77:**359-366

[9] Felton W.L., Marcellos H., Martin R.J. (1995) A comparison of three fallow management strategies for the long-term productivity of wheat in northern New South Wales. Aust J Exp Agric **35:**915-921

[10] Gallagher J.N. (1979) Field studies of cereal leaf growth. I. Initiation and expansion in relation to temperature and ontogeny. J Exp Bot **30:**625-636

[11] Gallagher J.N., Biscoe P.V., Wallace J.S. (1979) Field studies of cereal leaf growth. 4. Winter wheat leaf extension in relation to temperature and leaf water status. J Exp Bot **30:**657-668

[12] Harte A.J. (1990) The effects of tillage practice on the structural stability of three Vertisol soils of the northern New South Wales wheatbelt. M.Rur.Sci. Thesis. University of New England, Armidale

[13] Hay R.K.M., Delécolle R. (1989) The setting of rates of development of wheat plants at crop emergence: influence of the environment on rates of leaf appearance. Ann Appl Biol **115:**333-341

[14] Hay R.K.M., Tunnicliffe Wilson G. (1982) Leaf appearance and extension in field-grown winter wheat plants: the importance of soil temperature during leaf growth. J Agric Sci **99:**403-410

[15] Isbell R.F. (1996) The Australian Soil Classification. CSIRO Publishing, Collingwood

[16] Kirkegaard J.A. (1995) A review of trends in wheat yield responses to conservation cropping in Australia. Aust J Exp Agric **35:**835-848

[17] Kirkegaard J.A., Angus J.F., Gardner P.A., Müller W. (1994) Reduced growth and yield of wheat with conservation cropping. I. Field studies in the first year of the cropping phase. Aust J Agric Res **45:**511-528

[18] Large E.C. (1954) Growth stages in cereals, illustration of the Feekes scale. Plant Pathol **3:**128-129

[19] Lovett J.V., Jessop R.S. (1982) Effects of residues of crop plants on germination and early growth of wheat. Aust J Agric Res **33:**909-916

[20] Mason I.B., Fischer R.A. (1986) Tillage practices and the growth and yield of wheat in southern New South Wales: Lockhart, in a 450 mm rainfall region. Aust J Exp Agric **2:**457-468

[21] Norman M.J.T., Wetselaar R. (1960) Losses of nitrogen on burning native pastures at Katherine, N.T. J Aust Inst Agric Sci **26:**272-273

[22] Perry M.W., Belford R.K. (1991) The structure and development of the cereal plant. In: Perry M., Hillman B. (eds) The wheat book: a technical manual for wheat producers. Western Australia Department of Agriculture Bulletin 4196, pp 17-36

[23] Platz G.J., Rees R.G. (1989) Yellow spot of wheat: a conservation cropping dilemma. Queensland Agric J **115:**284-286

[24] Reeves T.G., Ellington A. (1974) Direct drilling experiments with wheat. Aust J Exp Agric Anim Husb **14:**237-240

[25] Reuter D.J. (1986) Temperate and sub-tropical crops. In: Reuter D.J., Robinson J.B. (eds) Plant analysis: an interpretation manual. Inkata Press, Melbourne, pp 38-99

[26] Seligman N.G., Loomis R.S., Burke J., Abshahi, A. (1983) Nitrogen nutrition and canopy temperature in field-grown spring wheat. J Agric Sci **101:**691-697

[27] Watts W.R. (1972) Leaf extension in Zea mays. II. Leaf extension in response to independent variation of the temperature of the apical meristem, of the air around the leaves, and of the root-zone. J Exp Bot **23:**713-721

[28] White P.J. (1984) Effects of crop residue incorporation on soil properties and growth of subsequent crops. Aust J Exp Agric Anim Husb **24:**219-235

[29] Wildermuth G.B., Thomas G.A., Radford B.J., McNamara R.B., Kelly, A. (1997) Crown rot and common root rot in wheat grown under different tillage and stubble treatments in southern Queensland, Australia. Soil Tillage Res **44:**211-224

[30] Wilkins D.E., Klepper B.L., Rasmussen P.E. (1988) Management of grain stubble for conservation-tillage systems. Soil Tillage Res **12:**25-35