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Influence of mulching on the pattern of growth and water use by spring wheat and moisture storage on a fine textured soil

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Abstract

Eight tonnes ha^{-1} of stubble were used to mulch spring wheat (*Triticum aestivum*) on a fine textured soil with the aim of controlling both transpiration and soil evaporation during the wet pre-anthesis phase to increase moisture supply during grain filling in the eastern wheatbelt of Western Australia. Mulching reduced leaf area per plant by reducing the culm number; consequently the green area index was reduced. Reduced culm number was associated with low soil temperature which at 50 mm depth averaged 7°C lower under the mulched crop relative to the control crop in mid-season. The smaller canopies of the mulched crop used 15 mm less water than those of the control before anthesis; this difference in water-use was due equally to reduced transpiration and soil evaporation. However, the mulched crop was unable to increase ET during grain filling, a response associated with the persistence of low soil temperature for most of the growth period. Hence, total ET for the season was significantly lower (18 mm) under the mulched crop than the control crop. At harvest, mulching did not have significant effects on total above-ground dry matter and grain yields, but it increased water use efficiency for grain yield by 18%, grain weight by almost 17% and available moisture in both uncropped and cropped plots by an average of 43 mm.

To determine whether there was any residual effects of soil treatment on moisture storage during the summer fallow period, soil moisture was monitored both in cropped plots and uncropped plots, that were either mulched or unmulched during the growing season, from harvest in October 1988 until next planting in June 1989. Available moisture at next planting was correlated with moisture storage at harvest despite the differences in run-off, soil evaporation and fallowing efficiency (increase in moisture storage as a percentage of rainfall) between treatments during fallowing. Therefore, the mulched treatments had more moisture available (30 mm), mostly as a result of less water use during cropping in the previous growing season, than the unmulched treatment.

The study shows that mulching may be used to restrain both transpiration and soil evaporation early in the season to increase availability of soil moisture during grain filling. Secondly, mulching during the previous growing season had little effect on soil moisture during the summer fallow period, however, the moisture saved by mulching during cropping was conserved for the following season. These results indicate the importance of evaluating mulching of winter crops in terms of crop yield in the subsequent growing season as well as in the current season in which the soil was treated.

Abbreviations: D – through drainage, DAS – days after sowing of the crop on 31 May 1988, DM – dry matter produced in the above-ground portion of the crop (kg ha^{-1}), E_0 – evaporation from Class A pan (mm), E_s – evaporation from uncropped soil (mm), E_{sc} – evaporation from soil beneath the wheat canopy (mm), ET – evapotranspiration (mm), FE – fallowing efficiency (gain in soil moisture storage/rainfall), GAI – green area index (area of green vegetation per unit land area), GWUE – water-use efficiency for grain production (grain yield/total ET, kg ha^{-1} mm^{-1}), K – extinction coefficient (see equation 1), RO – run-off of moisture from soil surface during/following rainfall (mm), SM – available soil moisture (mm) at harvest (SMh) or at planting (SMp), WUE – water-use efficiency for total above-ground dry matter yield (see GWUE).

Introduction

In environments where terminal drought limits grain yield, practices that restrain evapotranspiration (ET) early in the season, by controlling canopy development, should increase grain yield by improving the availability of moisture during the dry grain filling period (Pasioura, 1977). This concept of saving water early in the season was tested by Islam and Sedgley (1981) in the eastern wheatbelt of Western Australia on the heavy textured soil, where low infiltration and high native nitrogen levels cause rapid canopy development and depletion of soil moisture. They obtained between 14 and 22% increase in grain yield as a result of improved harvest index when spring wheat was surgically detillered at floral initiation stage. Also at the same site, moisture supply after flowering was increased by grazing and mowing annual legume pastures in the mid-season (Yunusa et al., 1992). Several other approaches have been used to achieve the same objective in grain crops by breeding and management practices, and have been reviewed by Sedgley (1991). However, mulching of the soil surface under crops is a significant management option, the potential of which to restrain early canopy development has not been fully assessed in the context of limiting transpiration early in the season in this environment.

Mulching inhibits crop growth as a result of reduced soil temperature caused by shielding of the soil surface from solar radiation (Enz et al., 1988). Low soil temperatures under mulches inhibit canopy development during the initial stages of growth directly (Black, 1970; Cochran et al., 1982; Wilkins et al., 1988) and/or indirectly by inhibiting nutrient, especially nitrogen, availability in the soil (Smika and Ellis Jr., 1971). Wraith and Hanks (1992) recently showed that low soil temperatures caused shallow rooting in wheat and corn, and reduced maximum depth of extraction of soil moisture by as much as 0.20 to 0.40 m. Hence, in addition to reducing soil evaporation under the crop canopy (E_{sc}) (Cochran et al., 1982; Wilkins et al., 1988), mulching may also reduce transpiration by inhibiting canopy development and rooting depth. However, this aspect is often neglected in most mulching studies.

As the mulch materials decompose the soil surface is exposed and the low temperature stress is lifted. Often the crops recover and take advantage of the increased moisture supply late in the season to increase grain yield (Black, 1970; Cochran et al., 1982; Wilkins et al., 1988). Thus mulching can be considered as increasing the partitioning of ET and dry matter production from pre-anthesis to the post-anthesis phase in conformity with the approach proposed by Passioura (1977). With the use of mulch in this way water use efficiency for the total above-ground dry matter yield (WUE) may remain unaffected, but the efficiency for grain yield (GWUE), i.e. harvest index, would be expected to increase.

The importance of available soil moisture at the start of the cropping season in determining yield in dry winter cropping environments has been emphasized (French, 1978; Fischer, 1987a). Fallowing, by which the land is kept free of plant growth, is practised to conserve soil moisture for future crops. However, French (1978a) found that in a dry Mediterranean environment of south west Australia moisture storage at the beginning of the growing season was correlated with rainfall during the previous growing winter season and not with rainfall during the summer fallow period. It is not clear to what extent practices such as mulching affect the amount of stored moisture at the end of the growing season and is conserved for the next cropping season.

The objectives of this study were to evaluate (1) the potential of using surface mulching to modify the patterns of growth and water-use in spring wheat in a way to increase available soil moisture during grain filling, and (2) the residual effects of the soil treatments on moisture storage during the following summer fallow period.

Materials and methods

Site

Field studies were undertaken at Merredin (31° 29′ S, 118°C 12′ E, 315 m altitude) in the eastern wheatbelt of Western Australia between June 1988 and June 1989. The climate is typically Mediterranean with mean annual rainfall of 310 mm. The mean air temperature rarely falls below zero although frosts do occur in some years; the mean growing season temperature is around 10°C. A brief description of the climate has been given previously (Rickert et al., 1987; Yunusa et al., 1992). Long term weather data as well as data for 1988 and 1989 are presented in Table 1. In 1988, January to March was drier than usual while April, August, September and December were wetter than expected. Pan evaporation (E_0) was lower than usual. Rainfall during the fallow period between November and June was above, while E_0 was below, expectation.

The experiment was carried out on a fine textured soil designated as Dr 2.13 (Nortcote, 1967) and classified as a Xeralfic Alfisol (Bettenay and Hingston, 1961). It has a duplex profile with a top 0.10-m of reddish brown sandy loam to clay loam over yellow sandy clay; pH of the soil increases from around 6.1 near the surface to 7.8 below 0.50 m depth. Details of both the physical and chemical properties of this soil have been published (Hamblin and Tennant, 1987).

Treatments and agronomy

Wheat seeds were sown on 31 May in 0.18 m rows in blocks 50 m long and 2.16 m wide so that each plot had 12 rows. Cultivar Gutha was used at the commercial sowing rate of 60 kg ha^{-1} for a density of 250 plants m^{-2}. At planting the site was supplied with 60 kg ha^{-1} of superphosphate (6% P) and 60 kg ha^{-1} of urea (46% N). Weeds were controlled with herbicides at recommended rates at planting and nine weeks after planting.

Six plots of 3.0 m long by 2.16 m wide (12 rows) were marked in mid June. A similar number of uncropped plots with the same dimensions to the cropped plots were marked on unsown bare soil. Two treatments each of cropped and uncropped plots were established, and mulch was applied to three randomly selected

Table 1. Meteorological variables at Merredin, Australia: Long term averages (LTA) and figures for 1988 and 1989[a]

Month	Rainfall (mm)			Pan evaporation (mm)		
	LTA	1988	1989	LTA	1988	1989
January	11	0	30	382	312	310
February	15	1	19	294	300	270
March	21	11	0	263	252	255
April	22	39	31	172	153	139
May	38	59	67	109	67	64
June	50	49	69	62	65	44
July	47	46	39	73	61	51
August	41	57	13	84	68	83
September	22	20	7	124	105	126
October	33	9	7	203	174	146
November	15	5	0	273	255	282
December	14	65	0	350	273	233
Total	329	361	282	2389	2085	2093

[a] Source: Bureau of Meteorology.

plots at 36 DAS, i.e. at floral initiation (Siddique et al., 1990). Thus the experimental design was a randomized complete block design of four treatments, two cropped and two uncropped:

1. Control crop: cropped but not mulched plots
2. Mulched crop: cropped and mulched plots
3. Un-cropped control: not cropped and not mulched plots
4. Un-cropped mulched: not cropped but mulched plots.

These were replicated three times. The uncropped treatments were located on the unsown portion of the paddock, about 10 m from the sown treatments; the whole paddock was under an annual legume pasture in the previous season. Two-year-old wheat straw that was baled and stored in a shed was used as mulch at the rate of eight tonnes per hectare. This high rate of wheat straw was used to achieve maximum effect of straw on wheat growth (Tennant, 1987). On each plot the outer two rows were considered as border rows, the next three rows following the border rows were used for periodic sampling, while the innermost four rows were taken as the harvest plot from which final yield samples were taken.

Measurements and observations

Plant growth and yield

Crop establishment was assessed at three weeks after planting. Date of anthesis was recorded on the day at least half of the plants had at least one dehisced anther. Date of physiological maturity was taken as the day grains in the basal spikelets were at hard dough stage.

The green area index (GAI) was determined from 10 adjacent plants taken from the buffer rows at fortnightly intervals, commencing at 35 DAS. The green areas of the leaf laminae (one side), stem, and later the ears were measured with a leaf area meter (LICor 3100, Li-Cor Devices, Nebraska, USA). The sum of all the green areas was used to determine GAI based on the number of plants in one square meter area. Dry matter (DM) produced was determined using the same plant samples as for GAI determination, but it also included any senesced parts that were present; the samples were oven dried at 70°C for 48 hours and weighed. Dry matter was also determined from large quadrats of four rows by half a meter length (0.36 m^2) taken from one end of each net plot at establishment and anthesis; these were used to check against the DM values obtained from the more frequent 10 plant samples. The number of plants in the net plots was also counted during the fortnightly sampling.

Crops were harvested on 25 October at 148 DAS. At this time a one-square metre quadrat (the four inner rows by 1.4 m length) sample was taken from each net plot for total above-ground dry matter and grain yields. The plants and ears in each quadrat were counted, the whole samples were then dried at 70°C for 48 hours and weighed. The ears were threshed and the grains weighed after drying. Mean grain weight was determined by counting and weighing 1000 grains per plot, after drying at 70°C for 48 hours.

Light interception

The fraction of photosynthetically active radiation (PAR) intercepted by the canopy (i) was determined with a 0.90 m long quantum sensor (LI-Cor LI-188) beginning at establishment and repeated at fortnightly intervals. Measurements were taken at a height of 1.5 m over the crop and below the canopy at ground level. In both cases the senor was placed horizontally and at right angle to the direction of crop rows. These data were used along with GAI data to calculate an extinction coefficient (K) by regression of In-(fraction of PAR transmitted through the canopy) against GAI using the relationship (Monteith and Unsworth, 1990):

$$\text{Intercepted PAR} = 1 - e^{-K.GAI} \qquad (1)$$

Soil moisture

Soil moisture content was determined using the neutron scattering technique. Access tubes for the moisture meter were installed in both the cropped and uncropped plots to depths of 1.20 m. The tubes were monitored starting from planting and thereafter at fortnightly intervals until harvest. Readings were taken at 0.10 m depth increments from 0.20 m to the lowest depth of the tubes. Moisture content in the top 0.20-m profile was determined by the gravimetric method. The ET was obtained as:

$$ET = P - (\Delta S + RO + D) \quad (2)$$

where P is rainfall, ΔS is change in soil moisture storage, RO is run-off and D is drainage. RO and D are rare on this soil (Rickert et al., 1987; Yunusa and Sedgley, 1992).

After harvest on 25 October 1988, it was difficult to keep the mulch in place due to strong winds, and so the straw was removed from all the plots two weeks later. The tubes were then monitored at least once a month until June 1989. However, RO occurred during the present study following 49 mm of rain on the night of 30 November – 1 December (186–187 DAS) and was calculated with Equation 2 taking bare soil evaporation (E_s) in the absence of crops, i.e. in the place of ET, for the measurement interval 170–200 DAS to be similar for all treatments; the E_s was obtained from a weighing lysimeter (Yunusa et al., 1992), which was also under bare fallow during the cropping season. ΔS was obtained from storage data taken on 170 and 200 DAS.

Soil available moisture (SM) was calculated as described previously (Yunusa et al., 1992) taking the profile of cropped control plots at two weeks after harvest as zero available soil moisture and that of mulched bare plots at 84 DAS, when storage was highest, as maximum available moisture. Fallowing efficiency (FE) for all the treatments was calculated as the ratio of change in moisture storage to rainfall over the summer period, expressed as a percentage (Fischer, 1987).

Soil temperature

Soil temperature at 50 mm depth was measured with an electronic thermometer (DIEAL Thermotron, Japan) between 1200 and 1300 local time. The sensor was placed in the soil between the crop rows and the reading taken after 30 seconds.

Weather variables

An automatic weather station about one kilometer away measured temperature, rainfall and wind run. These variables and E_0 were also measured at a standard weather station close to the trial. Potential evapotranspiration (E_{pot}) was determined with Penman-Monteith equation (Monteith and Unsworth, 1990).

Partitioning of evapotranspiration

Transpiration was estimated using the data for the fraction of intercepted solar radiation and available soil moisture. Maximum transpiration from a sparse canopy (T_p) was estimated from GAI and E_{pot} by Singh and Sri Rama (1989) using an equation similar to:

$$T_p = E_{pot}[(1 - \exp(-K.GAI)] \quad (3)$$

K was not included by Singh and Sri Rama, but included here since GAI alone may not always give a true measure of transpiration from a canopy (Monteith and Unsworth, 1990). Using microlysimeters (Boast and Robertson, 1982) on these soils, the ratio of actual transpiration (T) to T_p (i.e. T/T_p) was found to be close to unity until the fraction of available soil moisture fell to 0.40; below this value, T/T_p was related to SM as follows (Yunusa, 1992):

$$T/T_p = 0.014 + 2.25SM \quad (4)$$

Soil evaporation under the canopy (E_{sc}) was obtained as the difference between ET and transpiration.

Statistical analysis

All plant, ET and soil moisture data collected on the cropped treatments during the growing season were separately pooled for the analysis of variance; the soil moisture data for the uncropped treatment were analyzed separately. The soil moisture data from both the cropped and uncropped treatments were pooled for the analysis of variance in a split plot design using cropping as main treatments and mulching as sub-treatments.

Results

Crop growth

Over 80% emergence was achieved by two weeks after sowing; anthesis was at 105 DAS and maturity at 144 DAS. Plant numbers were similar in both the control and mulched treatments throughout the growing season, averaging 228 plants m^{-2} at establishment, 227 at anthesis and 210 at harvest. However, significantly fewer (22%) culms were produced per plant (Fig. 1a) by the mulched crop than the control crop after 80 DAS until a fortnight before harvest. The GAI (Fig. 1b) was consistently lower for the mulched crops than for the control crop between 60 and 100 DAS, but the difference was significant only between 72 and 100 DAS, during which period mulching reduced GAI by 20%. A K value of 0.52 was obtained for cv. Gutha. The rate of DM accumulation (Fig. 1c) was more rapid in the control (18.1 kg ha^{-1} day^{-1}) than in mulched (5.2 kg ha^{-1} day^{-1}) crop between 72 and 85 DAS. However, the trend was reversed between 85 and 99 DAS when the rates were 10 kg ha^{-1} day^{-1} for control crop and 21 kg ha^{-1} day^{-1} for the mulched crop. Between 99 DAS and harvest, DM accumulation was similar for the two treatments.

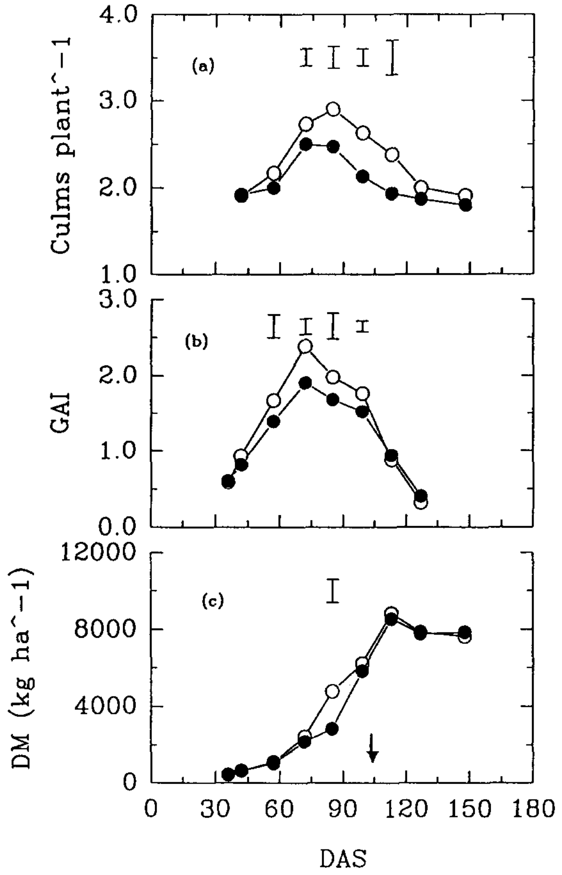

Fig. 1. Attributes of wheat growth for control crop (○) and mulched crop (●) at Merredin, Australia, in 1988: (**a**) number of culms produced per plant, (**b**) green area index (GAI), and (**c**) dry matter (DM) accumulation. Capped *bars* are LSD ($p \leq 0.05$) and the arrow indicates date of anthesis.

Crop water use

Mulching significantly reduced ET by 11% in the period before anthesis (Table 2); this was constituted by reductions of 8.5% in transpiration and of 16.7% in E_{sc}, although in real terms reductions in these components were almost the same, 8 and 7 mm respectively. During the post-anthesis phase mulching reduced transpiration by 17%, although ET was not significantly affected. At the end of the season ET was 9% (18 mm) lower for the mulched crop than for the control crop, most of which was due to reduced transpiration (14 mm) than suppression of E_{sc} (4 mm) by the mulched crop.

Mulching also significantly reduced E_s by 9.4% in the pre-anthesis phase (Table 2) but E_s was similar between the two treatments during the post-anthesis period. The seasonal E_s was almost 5% lower under mulch, but the difference was not significant.

Table 2. Evapotranspiration (ET), transpiration (T) and soil evaporation under canopies (E_{sc}) from the cropped treatments and soil evaporation from uncropped treatments (E_s) during the growing season at Merredin, Australia, in 1988

Treatments	Pre-anthesis (mm)				Post-anthesis (mm)				Total (mm)			
	ET	T	E_{sc}	E_s	ET	T	E_{sc}	E_s	ET	T	E_{sc}	E_s
Control	136	94	42	106	66	35	31	37	203	129	74	143
Mulched	121	86	35	96	64	29	35	40	185	115	70	136
LSD($p \leq 0.05$)[a]	12.5	na	na	7.6	NS	na	na	NS	18.3	na	na	NS

[a] na, not applicable.

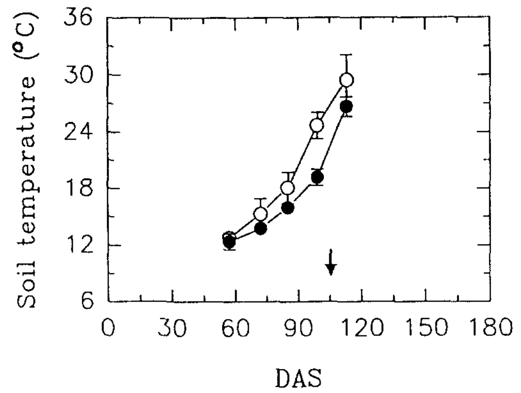

Fig. 2. Soil temperature at 50 mm depth under control crop (○) and mulched crop (●) treatments during the growing season at Merredin, Australia, in 1988. *Bars* are standard errors of the means and the *arrow* indicates time of anthesis.

Soil temperature

Mulching did not have a significant effect on soil temperature early in the season (Fig. 2); however, from 72 DAS the soil under the control crop was warmer than under the mulched crop, the differences continued to grow, reaching a maximum of 7°C at 99 DAS. At final measurement (105 DAS) the difference in soil temperature between the two treatments had fallen to 2.6°C, which was not significant.

Yields, yield components and water use efficiency

Mulching failed to significantly affect the final above-ground DM yield, grain yield, harvest index and ears m^{-2} (Table 3). However, the mulched crop produced significantly fewer but heavier grains than the control crop.

Mulching had no significant effect on WUE for the final above-ground DM and grain yields. However, mulching increased WUE by 6% and GWUE by 16%, although only the latter was significant (Table 3).

Soil moisture

Storage of soil moisture was normalized for all treatments at planting by taking a mean of all the tubes as the initial value (Fig. 3). Storage in the uncropped plots was not significantly affected by mulching throughout the study period. In contrast to the uncropped plots, storage of moisture in the top 0.2-m of the cropped plots (Fig. 3a) was similar between mulched and unmulched treatments during cropping, when rainfall was frequent (Fig. 3e). Mulching temporarily increased storage in the top profile following the heavy storm of 49 mm at the beginning of December. In both the 0.2–0.6-m (Fig. 3b) and 0.6–1.2-m (Fig. 3c) depth intervals, storage was higher with mulching for most of the cropping season until beginning of December when the drier profiles of the unmulched plots gained more moisture than the moister profiles of the mulched plots. During a period of frequent rainfall between April and June 1989, increase in moisture storage in the 0.2–0.6-m depth was greater with mulching compared to the control. The storage in the 0.6–1.2-m depth interval was consistently higher for the mulched crop, but not significantly, from anthesis until next planting.

Table 3. Yields and components of grain yield for spring wheat at Merredin, Australia, in 1988

Variables	Control	Mulched	LSD ($p \leq 0.05$)
Yields and yield components			
Total above-ground DM yield (kg ha^{-1})	8173	7846	NS
Grain yield (kg ha^{-1})	2049	2163	NS
Harvest index	0.25	0.28	NS
Number of ears (m^{-2})	337	341	NS
Number of grains (m^{-2})	8042	7502	226.2
Mean grain weight (mg)	24.8	28.9	1.85
Water use efficiency (kg ha^{-1} mm^{-1})			
Total above-ground DM yield	39.9	42.3	NS
Grain yield	10.1	11.7	1.22

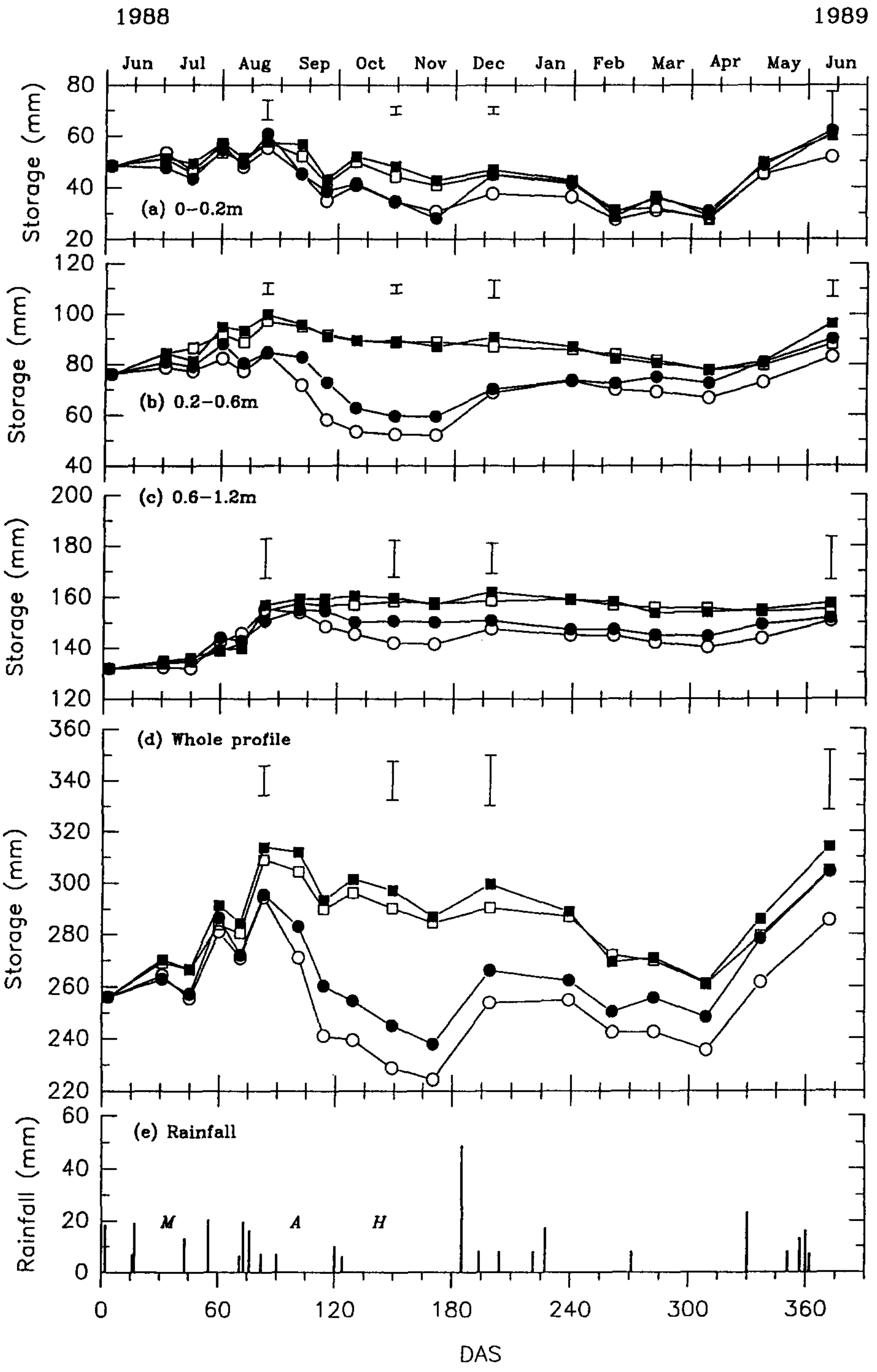

Fig. 3. Soil moisture storage under uncropped control (□), uncropped mulched (■), control crop (○) and mulched crop (●) at various depth intervals ((**a**) to (**d**)); and (**e**) main rainfall events at Merredin, Australia, in 1988/89. Capped *bars* are LSD ($p \leq 0.05$); in (**e**) letters *M* denote when mulch was applied, *A*, anthesis and *H*, harvest.

Table *4*. Effects of previous soil treatments on available soil moisture at harvest in 1988 (SMh) and at the start of new planting season in 1989 (SMp), run-off, soil evaporation (E_s) and on fallowing efficiency (FE) during the 1988–89 fallow period on a fine textured soil at Merredin, Australia

Treatments	SMh (mm)		Run-off (mm)		E_s (mm)		SMp (mm)		FE (%)	
	Uncropped	Cropped	Uncropped	Cropped	Uncropped	Cropped	Uncropped	Cropped	Uncropped	Cropped
Control	75	6	29	7	168	131	83	70	3	26
Mulched	103	35	22	6	163	144	119	94	8	27
P > F and (SE)										
mulch × cropping	0.8343		0.1461		0.0410 (2.3)		0.5949		0.585	
mulch	0.0212 (4.9)		0.0714		0.4696		0.0507 (7.8)		0.3948	
crop	0.0072 (4.9)		0.003 (1.6)		0.0002 (2.1)		0.4665		0.0020 (2.1)	

Therefore, while total moisture storage in the 1.2-m profile (Fig. 3d) was not significantly affected by mulching, storage in the cropped treatments was increased by mulching from anthesis in September to December 1988 and from April to June 1989.

Changes in the soil moisture status and associated characteristics during fallow between harvest in 1988 and next planting in 1989 are summarized in Table 4. At harvest storage of available soil moisture was increased by both mulching and absence of cropping during the growing season. Run-off was not affected by mulching but was significantly reduced (28%) in the previously cropped plots. Soil available moisture at planting in 1989 was significantly increased (average of 39%) by mulching in the previous season for both cropped and uncropped plots. Cropping in the previous season did not significantly affect available moisture at next planting. Rainfall during the fallow period totalled 286 mm, but fallowing efficiency (Table 4) was not significantly affected by mulching during the previous season, however, cropping in the previous season significantly increased fallowing efficiency during fallow.

A regression of available soil moisture at planting on the other variables in Table 3, produced a significant correlation ($r^2 = 0.55$, $n - 2 = 10$) only with available soil moisture at harvest.

Discussion

Mulching reduced ET in the pre-anthesis period by restraining transpiration in addition to E_{sc} (Table 2). Although, transpiration was proportionately reduced to a lesser extent than E_{sc}, in real terms almost the same amounts of water were saved through both processes, about 8 mm. Low rates of transpiration by the mulched crop was caused by retarded canopy development which derived from the fewer culms produced per plant (Fig. 1). The leaf area produced per plant was correlated ($r^2 = 0.76$, $n = 30$) with culm number per plant during the pre-anthesis period.

Lower pre-anthesis ET for the mulched crop ensured greater soil moisture storage under this treatment than under the control crop during grain filling (Fig. 3). However, the mulched crop did not increase ET after anthesis (Table 2) in contrast to the results from other studies (e.g. Cochran et al., 1982). Cochran et al. applied high rates of nitrogen (140 kg ha^{-1}) which could have ameliorated most of the effects of low soil temperatures on nitrogen availability. Furthermore, Cochran's group sited their study where the growing season was longer (about nine months) than at Merredin (about five months), and could have provided a greater opportunity for the straw materials to decompose and aided in alleviating any effects of low soil temperature before termination of growth. In the present study, therefore, the persistence of low temperatures under mulched crop during most of the growth period (Fig. 2) perhaps inhibited deep rooting which probably accounted for the greater moisture storage under the mulched crop during the post-anthesis phase (Fig. 3). Hence, the pre-anthesis to post-anthesis ratio for ET remained largely unaffected by mulching (Table 2).

However, mulching increased GWUE (Table 3) not as a result of greater DM production after anthesis compared to the control crop, as would be expected under the water saving concept, but because of reduced total water use during the season. The higher ET by the control crop, compared to the mulched crop, was not translated into increased yields at harvest (Table 3); this could be accounted for by the large number of culms produced early in the season, most of which were lost before anthesis (Fig. 1). This response is consistent with the analysis of both Sedgley (1991) and Yunusa and Sedgley (1992) who stated that tillering should be limited on this soil to reduce the size of the vegetative parts of the plant to provide more water and assimilates for grain filling. The similarity in grain yield and harvest index between the two treatments (Table 3) is consistent with similarity in ET (Table 2) and accumulation of dry matter (Fig. 1) by the mulched and control crops after anthesis. However, the fewer grains produced by the mulched crop ensured greater availability of assimilates per grain.

The conclusion drawn from the cropping experiment is that the concept of saving water by limiting canopy development early in the season can be achieved by mulching. Although in this study, the water saved was not used after anthesis, perhaps application of fertilizer N just before anthesis could have ensured utilization of this moisture to increase grain yield.

Soil treatment during the growing season had a large effect on the amount of moisture stored at the end of the growing season and conserved for the following cropping season (Table 4). The maintenance of the difference in available moisture at harvest in 1988 between mulched and unmulched treatments throughout the fallow period indicated that the residual effects of mulching during cropping on the events of the fallow period was not significant.

In contrast to mulching, however, cropping in the previous season significantly increased soil moisture storage during the fallow period by increasing the fallowing efficiency, such that the difference between cropped and uncropped treatment at harvest in 1988 disappeared by June 1989 (Table 4). Storage at planting for the previously cropped treatments was aided by low rates of E_s during fallow consistent with their initially drier profile compared to uncropped control plots; also the infiltration of rain water and its subsequent redistribution to the deep layers were greater (Fig. 3), while run-off was lower (Table 4) as would be expected (Hillel, 1976). Hence, the low fallowing efficiency in the ex-bare treatments compared to ex-crop treatments is in accordance with the analysis of Fischer (1987) by which 'wet start' fallows (initially wet soil profiles) loose large amounts of moisture through sustained high rates of E_s; 'dry start' fallows (initially dry soil profiles), on the other hand, produce high fallowing efficiency by having initially low rates of E_s and comparatively rapid rate of moisture infiltration during rainfalls. The small amounts of run-off on the ex-crop treatments compared to uncropped plot could be attributed to a better soil structure at the surface of the former, which was protected from the ponding by rain-drops during the previous wet winter (Hamblin, 1984).

It should be noted, however, that this fallow period (November 1988 to May 1989) was unusually wet (Table 1) and must have enhanced recharge of the previously cropped plots more than would be expected. It is doubtful if recharge of the cropped profile would be this rapid in a normal season. Although this study was not carried through the next cropping season, the additional 30 mm of water made available in June 1989 by mulching in 1988 could be expected to increase grain yield by 240 kg ha^{-1} (French, 1978b). In this environment effective mulching may be limited by low stubble yields, which are often less than the eight tonnes ha^{-1} used in the present study (Tennant, 1987); but Tennant found two tonnes ha^{-1} of stubble to be as effective as eight tonnes in conserving soil moisture in uncropped plots. Whether this can equally restrain canopy growth is not certain.

The main conclusion from the fallow period data, therefore, is that although mulching had no significant residual effects on moisture storage during the summer fallow period, it still increased available moisture at next planting by conserving moisture from the preceding cropping season.

These results show that mulching may be used to increase moisture supply to the crop during grain filling by restraining both transpiration and E_{sc} during the wet pre-anthesis phase. They also indicate the importance of evaluating mulching of winter crops in terms of crop yield in the subsequent growing season as well as in the current season in which the soil was treated.

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