The partitioning of evapotranspiration of irrigated wheat as affected by rice straw mulch

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Abstract
Soil evaporation is considered to be a non productive component of evapotranspiration (ET). Measures which moderate soil evaporation may influence the amount of water available for transpiration, the productive component of ET. Field experiments investigating the effect of rice straw mulch on components of the water balance of irrigated wheat were conducted during 2006-07 and 2007-08 in Punjab, India, on a silt loam soil. Daily soil evaporation (Es) was measured using mini-lysimeters, and total seasonal evapotranspiration (ET) was estimated from the water balance equation using measurements of irrigation, rainfall and soil water depletion. The mulch lowered total soil evaporation over the crop growth season by 35 and 40 mm in relatively high and low rainfall years, respectively. Much of this "saved water" was partitioned into transpiration, which increased by 30 and 36 mm in the high and low rainfall years, respectively. As a result, ET was not affected by mulching in either year. This is a very important finding in relation to the potential for mulching to save water and increase WP_{ET}. In both years, there was significantly higher tiller survival and grain weight with mulching, and this led to significantly higher grain and total biomass yields in 2006-07, probably because the non-mulched treatment suffered from water deficit stress for a period after maximum tillering that year. Transpiration water productivity with respect to grain yield was 18.8-19.1 kg/ha/mm in 2006-07, and 14.6-16.1 kg/ha/mm in 2007-08. There was trend for mulch to lower transpiration water productivity, significantly in 2007-08. The results suggest that while mulching of well-irrigated wheat reduces soil evaporation, it does not "save" water because the crop compensates by reduced transpiration efficiency.

Key Words
Soil evaporation, transpiration efficiency, north-west India

Introduction

In the intensive irrigated rice-wheat (RW) systems of Punjab, India, wheat occupies 3.5 Mha, of which 2.6 Mha follows immediately after rice. Rice residues are normally burnt prior to wheat sowing, creating severe air pollution and loss of nutrients. Recent machinery developments enable simultaneous mulching of rice residues as well as the direct drilling of wheat in to these residues (Sidhu *et al*. 2007). The presence of rice residues on the soil surface may produce benefits such as reduction in soil evaporation. Soil evaporation (Es) is considered to be a non-beneficial loss of water, aside from its effects of moderating air and canopy temperature and humidifying the air (Leuning *et al*. 1994). Mulching offers the potential to reduce soil evaporation by the interception of solar radiation and reduction of wind speed close to the soil surface. In semi arid regions, the Es component of total seasonal evapotranspiration (ET) of annual crops accounts for 30 to 70% of ET (Zhang *et al*. 1998), and is important in irrigated cropping systems like the irrigated RW systems in north-west India where the soil is frequently subjected to wetting and drying cycles. Therefore, measures which offers the potential to reduce soil evaporation such as mulching are of interest for their potential to reduce water loss and increase water productivity.

Several recent studies in north-west India showed that soil water content was higher under wheat mulched with rice straw than without mulch (Sidhu *et al*. 2007; Yadvinder-Singh *et al*. 2008), but in these studies no attempt was made to quantify the effect of the mulch on ET, or to partition this into effects on Es and transpiration (T). Decreasing Es may lead to increased T as a result of both higher vapour pressure deficit and by preserving more water for T in water limited environments (Eberbach and Pala 2005) and result in more yield as a result of the linear relationship between T and biomass production as suggested by Passioura (1977). Therefore, in calculations of water use efficiency and in modelling studies, it is necessary to measure and simulate Es and T separately and accurately.

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Several approaches have been used to separate the Es and T components of ET. Direct measurement of Es has been made successfully using mini lysimeters placed between rows (Allen 1990). In the present study, we measured Es for the whole season using mini lysimeters to study the effect of mulch on the partitioning of ET in irrigated wheat in Punjab, India. Our hypothesis was that mulching would reduce soil evaporation, with the amount offset conserved for transpiration.

Methods

Field experiments were conducted in 2006-07 and 2007-08 at the Punjab Agricultural University farm at Ludhiana (30°56'N, 75° 52'E, 247m ASL), Punjab, India, on a silty loam soil. Two residue management treatments (mulch, non-mulch) were implemented in 12 m x 6 m plots with 4 replicates in a random block design. The preceding rice crop at the experimental site was harvested by combine harvester in mid-October each year, leaving standing straw (20-25 cm) and loose residues (total residues 8.3 t/ha). Rice straw was removed mechanically from the non-mulch plots, leaving stubbles about 2-3 cm high. Wheat (var. PBW343) was sown (100 kg/ha) using the Combo Happy Seeder (Sidhu *et al*. 2007) on 6th November 2006 and 13th November 2007 and grown using recommended practices. Nitrogen (60 kg N/ha: 50 kg N/ha as urea and 10 kg/ha as diammonium phosphate) and 26 kg P/ha (as diammonium phosphate), were banded with the seed, and a further 60 kg N/ha was applied as urea broadcast, at the time of crown root initiation (before the first irrigation after sowing). Weeds were controlled chemically by spraying Leader (Sulfosulfuron) @ 32.5g/ha and 2, 4-D @ 625g/ha after the first irrigation. After that, irrigations were scheduled using the ratio I:(CPE-rain) = 0.9 where I is the irrigation amount (75 mm for all irrigations) and CPE is net cumulative pan evaporation since the last irrigation. Irrigation volume was measured with a Wolman helical turbine meter.

Volumetric soil water content (SWC) was determined to a depth of 180 cm at sowing and harvest from gravimetric SWC and bulk density. In addition, neutron counts were made to a depth of 165 cm approximately twice weekly, and immediately before each irrigation, in all 4 replicates, using a CPN 2007 neutron moisture meter. The neutron moisture meter was calibrated for each soil layer separately over a range of values of SWC.

Soil evaporation below the wheat canopy was measured directly using mini-lysimeters which were weighed manually daily (at 24 h intervals). The mini-lysimeters consisted of open PVC cylinders 20 cm deep, 10 cm outside diameter, installed mid-way between the crop rows. After 5 days, fresh soil cores were installed in the lysimeters.

Evapotranspiration (mm) was estimated using a standard water balance equation: ET=dSWC+P+I-D-R, where dSWC is the change in soil water content (0-180 cm) between consecutive neutron probe readings, P is precipitation, I is the amount of irrigation and D is the drainage beyond 180 cm. Drainage was assumed to be negligible as tensiometers installed at 120, 140, 160 and 180 cm suggested no water movement beyond 120 cm (there was no change in soil matric potential at any of these depths following irrigation or rain). There was no runoff (R=0) from the plots.

Results and discussion

Total rainfall during the 2006-07 wheat season was 159 mm and was well distributed, so there was only one post-sowing irrigation. The 2007-08 season was generally dry, with total growing season rainfall of 88 mm received late in the season, and three post sowing irrigations were applied. Total crop ET was not affected by mulching, and was 341-345 and 400-404 mm in 2006-07 and 2007-08, respectively (Table 1). Cumulative Es in the non-mulched crop was 135 and 162 mm in 2006-07 and 2007-08, respectively, which is equivalent to 39 and 40% of ET each season. With mulch, calculated cumulative Es was reduced significantly to 100 and 121 mm, equivalent to 29 and 30% of ET in respective years. Transpiration was significantly higher with mulch in each year. During the early part of the crop growth season when LAI was low (up to 40-45 days after sowing), Es was the major part of ET (Figure 1). During this period, soil water content (0-15 cm) in the mulched wheat was significantly higher than without mulch and ensured more water for transpiration later in the season.

There was a trend for higher grain yield and total biomass with mulching, and the differences were significant in 2006-07 (Table 1). This was due to significantly higher spike density and grain weight, the benefits of which were offset by significantly fewer grains per spike each year (data not presented). The lower spike density without mulch was associated with higher tiller mortality, especially in 2006-07. The reason for the high tiller mortality without mulching in 2006-07 is probably due to soil water deficit stress for about 10 days after maximum tillering, as evidenced by tensiometer data (not presented). If so, this would suggest that an IW/(CPE-rain) ratio of 0.9 is sub-optimal in some seasons. Each year, post-anthesis biomass accumulation was greater in the mulched treatments, and post-anthesis transpiration was significantly higher in the mulched treatment. This is consistent with the findings of others that transpiration is directly linked with crop biomass production (Passioura, 1977). The higher grain yield with mulching in 2006-07 is consistent with the finding that 70-90% of grain yield is from post anthesis photosynthesis (Bidinger *et al.*, 1977).

Table 1. Soil water balance components and transpiration efficiency under mulch and non mulched wheat during 2006-07 and 2007-08.

	2006-07			2007-08		
	Mulch	Non-Mulch	L.S.D (0.05)	Mulch	Non-Mulch	L.S.D (0.05)
Irrigation (mm)	75	75	-	225	225	-
Rain (mm)	159	159	-	88	88	-
dSWC (mm)	-107	-111	NS	-87	-91	NS
ET (mm)	341	345	NS	400	404	NS
Soil evaporation (mm)	101	135	10	121	161	17
Transpiration (mm)	240	210	26	279	242	29
Grain yield (t/ha)	4.5	4.0	0.2	4.1	4.0	NS
Total biomass (t/ha)	10.6	9.2	0.7	10.2	10.0	NS
Grain transpiration efficiency (kg grain/mm/ha)	18.8	19.1	NS	14.6	16.4	1.2
Total biomass transpiration efficiency (kg/mm/ha)	43.9	43.8	NS	36.6	41.4	3.1

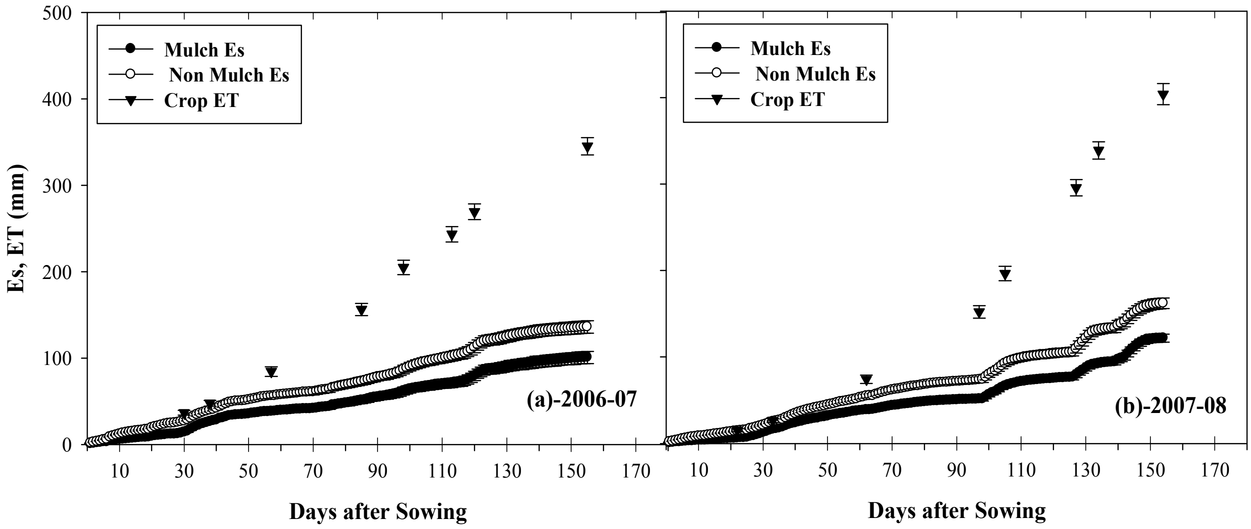

Figure 1. Cumulative soil evaporation (Es) and evapotranspiration (ET) with and without mulch during (a) 2006-07 (b) 2007-08.

There was a consistent trend for lower grain and total biomass transpiration efficiency with mulching, and the differences were significant in 2007-08 (Table 1). Grain transpiration efficiency was close to values observed for wheat elsewhere (Zhang *et al.* 1998). The lower transpiration efficiency with mulch may result from a low ratio of photosynthesis to transpiration at the leaf level under conditions of high water availability. Chakraborty *et al.* (2008) observed continuous low canopy temperature under mulch, and suggested that this was because the stomata remained open for longer periods, leading to higher transpiration and thus a lower photosynthesis/transpiration ratio.

Conclusions

Mulching suppressed soil evaporation by 35-40 mm and increased transpiration by a similar amount between anthesis and maturity of irrigated wheat. This was true in both a year of well-distributed rain (one post sowing irrigation only), and in a relatively dry year when 3 irrigations were required. As a result, water loss as ET was not affected by mulching in either year. This is a very important finding in relation to the potential for mulching to save water and increase WP_{ET}, and warrants further investigation.

Mulching reduced tiller mortality and increased post-anthesis biomass production in both years, and this resulted in significantly higher grain and biomass yields in the higher rainfall year. This, together with soil matric potential observations, suggests that the non-mulched treatment may have suffered from water deficit stress during that year, and that an I/(CPE-rain) ratio of 0.9 may be suboptimal in some seasons.

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References

Allen SJ (1990) Measurement and estimation of evaporation from soil under sparse barley crops in northern Syria. *Agricultural and Forest Meteorology* **49**, 291-309.

Bidinger F, Musgrave RB, Fischer RA (1977) Contribution of stored pre-anthesis assimilate to grain-yield in wheat and barley. *Nature* **270**, 431-433.

Chakraborty DN, Aggarwal S, Gupta P, Tomar VK, Garg RK, Sahoo RN, Sarkar RN, Chopra A, K.Sarma U, Kalra, KSSN (2008) Effect of mulching on soil and plant water status, and the growth and yield of wheat (Triticum aestivum L.) in a semi-arid environment. *Agricultural Water Management* **95**, 1323-1334.

Eberbach PL, Pala M (2005) Crop row spacing and its influence on the partitioning of evapotranspiration by winter-grown wheat in Northern Syria. *Plant and Soil* **268**, 195-208

Leuning R, Condon AG, Dunin FX, Zegelin S, Denmead OT (1994) Rainfall interception and evaporation from soil below a wheat canopy. *Agricultural and Forest Meteorology* **67**, 221-238.

Passioura JB (1977) grain-yield, harvest index, and water-use of wheat. *Journal of the Australian Institute of Agricultural Science* **43**, 117-120.

Siddique KHM, Tennant D, Perry MW, Belford RK (1990) Water use and water use efficiency of old and modern wheat cultivars in a Mediterranean-type environment. *Australian Journal of Agricultural Research* **41**, 431-447.

Sidhu HS, Manpreet-Singh, Humphreys E, Yadvinder-Singh, Balwinder-Singh, Dhillon SS, Blackwell J., Bector V, Malkeet-Singh, Sarbjeet-Singh (2007) The Happy Seeder enables direct drilling of wheat into rice stubble. *Australian Journal of Experimental Agriculture* **47**, 844-854.

Yadvinder-Singh, Sidhu HS, Manpreet-Singh, Humphreys E, Kukal SS, Brar NK (2008) Straw mulch, irrigation water and fertiliser N management effects on yield, water use and N use efficiency of wheat sown after rice. In ‘Permanent beds and rice-residue management for rice-wheat systems in the Indo-Gangetic Plain’. (Eds Humphreys E, Roth CH). Proceedings of a workshop held in Ludhiana, India, 7-9 September 2006. ACIAR Proceedings No. 127. Australian Centre for International Agricultural Research (Canberra, Australia), pp. 171-181. http://www.aciar.gov.au/publication/term/18.

Zhang H, Oweis TY, Garabet S, Pala M (1998) Water-use efficiency and transpiration efficiency of wheat under rain-fed conditions and supplemental irrigation in a Mediterranean-type environment. *Plant and Soil* **201**, 295-305.