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Application of mulch under reduced water input to increase yield and water productivity of sweet corn in a lowland rice system

L.K. Vial[a,*], R.D.B. Lefroy[b], S. Fukai[a]

[a] The University of Queensland, School of Agriculture and Food Sciences, Brisbane, Australia
[b] Centre for International Agriculture in the Tropics, Hanoi, Viet Nam

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ABSTRACT

While straw mulch usually reduces soil evaporation and stabilizes soil temperature, hence increasing yield, this effect may depend on the irrigation water input conditions. Two experiments in lowland rice paddies in Lao PDR tested the effect of rice straw mulch under various water input—standard farmer condition to reduced input condition by using either drip irrigation or lower furrow irrigation water input (WI) by increasing the furrow irrigation interval before flowering—on growth and yield of sweet corn. The time course of water balance components was determined to elucidate the mechanisms of mulch and water input interaction for row planted maize after rice harvesting.

The experiments found that adding straw mulch reduced estimated soil evaporation by 114–163 mm, but only some of this was partitioned into extra transpiration, so the non-transpiration flux (the difference between water input and transpiration) changed little. Only when mulch was added and water input also reduced did it maintain or increase transpiration, reduce the non-transpiration flux and hence substantially increase water productivity (WP). Most if not all of the non-transpiration flux occurred in the first 60 days; the opportunity to apply treatments to increase water productivity arose mostly in the first 60 days.

Mulch had a greater effect with extended furrow irrigation intervals before flowering than with standard intervals, but there was no effect under drip irrigation. In Experiment 1, mulch increased fresh ear yield and water productivity to water input (irrigation plus rainfall) (WP) by 42% with Low WI, but had no effect with High WI or with drip irrigation. The combination of mulch and reducing water input from High WI to Low WI increased gross margin (GM) per hectare by 20% and GM per m^3 water input by 66% due to increased yield and reduced water and labour costs. In Experiment 2, mulch increased fresh ear yield, WP by 93% and consequent GM with low WI, but also increased fresh ear yield and WP by 60% and GM with High WI.

In these Southeast Asian experiments, mulching and reducing water input—by increasing irrigation interval before flowering—maintained or increased yield, and increased gross margin per hectare and per m^3 water input. Particularly in areas with restricted water supply, and hence the need to reduce water input and increase water productivity, mulch allows a reduction in water input while also maintaining or increasing farm income from sweet corn.

1. Introduction

Straw mulch reduces the net radiation flux and soil evaporation (Allen et al., 1998) and maintains greater soil water content, particularly in the "first-stage" of soil drying when the soil surface is wet and evaporation is limited by the energy flux onto the soil surface (Unger and Parker, 1976). Singh et al. (2011), for example, reduced soil evaporation by 25% or 35–40 mm with 8–9 t ha^{-1} of rice straw under wheat in India's Punjab. Mulch application also increases the reflection of solar radiation in the day and decreases radiation heat loss from the soil at night, resulting in increased minimum temperature and decreased maximum temperature and hence reducing diurnal variation in topsoil temperature (Gill et al., 1996; Lal, 1973).

Having topsoil water content closer to field capacity and a less-variable soil temperature generally favours crop growth and yield (Lal, 1973, 1978), particularly for soils with low readily available water-holding capacity (Tolk et al., 1999) or low albedo (Lal, 1973).

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[*] Corresponding author. Present address: International Rice Research Institute, DAPO Box 7777, Metro Manila 1301, Philippines. Tel.: +63 917 564 8524.
E-mail address: l.vial@irri.org (L.K. Vial).

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Higher soil water content in the surface soil and less diurnal topsoil temperature variation can also increase nutrient uptake (Singh et al., 2005), which would exacerbate the effect of mulch on growth and development. Hence, mulch often increases the yield of non-rice crops on paddy soils, where the topsoil has poor structural porosity and the hardpan restricts subsoil root access (Gill et al., 1996; Lian, 1990), although the increased soil water content can increase the risk of waterlogging on paddy soils with limited internal drainage in periods of frequent rainfall and low vapour pressure deficit (Polthanee, 2001; Vial et al., 2013). When crops would experience "moderate levels of drought" between rainfall or irrigation events (Tolk et al., 1999), for example, 7–10 days in a tropical African environment (Lal, 1978), mulch provides the greatest yield benefits. Over shorter intervals bare soil does not dry enough for mulch to be an advantage, and as soil water is exhausted by transpiration over a longer interval, the growth benefit declines. Gill et al. (1996) increased maize yield by only 0–5% with mulch with shorter irrigation intervals but by 19–35% with longer irrigation intervals, but Singh and Sudanshu (2005) found no interaction between mulch and irrigation interval in maize grain yield on a rice soil in Bihar, India. In Texas, mulch increased maize yield by 33% on a soil similar to a paddy soil, independent of irrigation treatment (Tolk et al., 1999).

The greater leaf area later in the growing season as a result of mulch application may, however, increase the canopy transpiration rate and create greater drought stress later within an irrigation cycle, particularly if the soil water storage capacity is limited (Tolk et al., 1999). This may result in a similar or even lower growth rate during later growth stages if extended irrigation intervals are used, as observed with mulched irrigated feed maize in lowland Lao PDR (Vial, 2012).

Water productivity to water input—the quotient of yield and water input—can be improved by any action that increases yield or decreases water input. Expressed in a different way, any action that decreases the amount of water that is not transpired (non-transpiration flux), while maintaining or increasing transpiration, will increase water productivity. However, reduced water input may result in lower water productivity, particularly if it affects reproductive processes and yield as found in soybeans in Punjab rice soil (Arora et al., 2011). Mulch can increase water productivity by reducing evaporation losses, provided that transpiration and consequent yield increases or water input declines (Bouman, 2007). Tolk et al. (1999) found that mulch increased maize water productivity by increasing yield with no interaction with water input, but the water input was relatively low for both irrigation treatments (150 mm and 50 mm) in an experiment on a Texas soil similar to a paddy soil. Gill et al. (1996) did not show any increase in maize water productivity from mulch in a Punjab rice soil when water input remained high, but increased it by 46% when water input was decreased. This experiment was conducted very late in the dry season, however, when temperatures were high and evaporation was 8–10 mm day^{-1}, compared with 3–6 mm day^{-1} in the dry season in Southeast Asia, and rainfall substituted for irrigation in the last half of the season. Singh et al. (2011) was the only comparable study using retained straw mulch that measured water balance components; finding that mulch reduced evaporation by 35–40 mm, and most of this was converted to extra transpiration, although not reliably to extra grain yield of wheat.

The aim of this work is to measure the water balance components of sweet corn with and without mulch in southeast Asia for the first time, and assess whether straw mulch has a greater effect on the water balance components, yield and consequent water productivity of dry-season sweet corn with reduced water input in a Southeast Asian rice system. It also aims to give basic economic outcomes from mulching in this context.

2. Materials and methods

Mulch application was investigated in three experiments in Vientiane Province, Lao PDR (18°24.5′ N, 102°31.5′ E): a preliminary experiment in Pakcheng, 2008–09, and experiments 1 and 2 in Pakcheng and Ban Keun Neua, 2010–11.

2.1. Preliminary experiment

The preliminary experiment was conducted in a farmer's rice field with a loamy-clay soil in Pakcheng Village. The field was ridged at a spacing of approximately 1.2 m and sweet corn (variety Supersweet) planted on 18 January 2009, on either side of each ridge at approximately 0.6-m spacing. The mulch was applied on top of the ridge covering the entire inter-row space and in the plant row at a rate of about 4 t ha^{-1} except for alternate furrows so as to allow the free passage of irrigation water; hence, about 60% of the crop area was mulched. The experiment was a randomized block design with two levels of surface soil treatment (bare soil and mulched) and three replicates.

The same fertilizer application (200 kg ha^{-1} 15-15-15 (N-P_2O_5-K_2O) basally and 200 kg ha^{-1} 46-0-0 topdressed after 30 days) and same irrigation schedule were applied to the sweet corn with bare and mulched soil.

The height of 10 plants was measured at 28 and 62 days after seeding (DAS). The experiment was harvested at 95 DAS; the central four rows of each plot were harvested, except for 1 m at each end of each plot. The harvest area, plant number, ear number, ear fresh and dry weight and stover fresh and dry weight were measured.

2.2. Experiments 1 and 2

Experiment 1 was in a farmer's field adjacent to that of the preliminary experiment in Pakcheng Village. Experiment 2 was in a farmer's field directly across the Nam Ngeum River from Pakcheng in Ban Keun Neua; the soil was a clay-loam, which had had wet-season rice every year since the early 1990s and sweet corn every dry season since 2001. Farmers at both locations supplied sweet corn to the nearby Lao Agro-Industries factory.

The experiments were a factorial design, with three replicates in Experiment 1 and four replicates in Experiment 2. There were two soil surface treatments (bare soil and mulched) in both experiments, with three irrigation treatments in Experiment 1 and two irrigation treatments in Experiment 2. All plots were 7.5 m long and had eight rows, including two guard rows on each side to accommodate destructive biomass harvests during the season and retain sufficient final harvest area.

2.2.1. Treatments

Both experiments 1 and 2 had High and Low water input (WI) treatments, and Experiment 1 also had a drip irrigation treatment. The High WI treatment was similar to that used by farmers in that area on sweet corn with bare soil. With every High or Low WI irrigation event, 56 mm was applied, and the timing of irrigation was based on crop evapotranspiration (ET_C), estimated from a Class A evaporation pan.

$$ET_C = E\,K_E K_C \tag{1}$$

where E is the evaporation from a Class A evaporation pan (mm); K_E is the evaporation factor, assumed as 0.8, to convert pan evaporation into reference evapotranspiration (Allen et al., 1998); and K_C is the tabulated crop factor (Allen et al., 1998) that did not differentiate for any differences in growth between the treatments.

In High WI, irrigation occurred when estimated cumulative evapotranspiration since the last irrigation event (ΣET_C) with a bare soil (Allen et al., 1998) reached 10 mm in the first 15 days, and then