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Yield advantage and water saving in maize/pea intercrop

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ABSTRACT

Intercropping is a well-established strategy for maximization of yield from limited land, but mixed results have been obtained as to its performance in terms of water use efficiency. Here, two maize/pea intercrop layouts were studied in comparison to sole maize and sole pea with and without plastic cover on maize to reduce evaporation. Growth patterns over time and yield were determined. Profiles of soil water content over depth and across rows in the intercrop were measured at three times to quantify water extraction and its spatial and temporal distribution. Several indices were calculated to characterize the efficiency of land and water use of intercrops as compared with sole crops of maize and pea. Land equivalent ratio ranged from 1.18 to 1.47, indicating that intercropping was an effective strategy for maximizing land use efficiency. Water equivalent ratio, WER, defined to characterize the use efficiency of the water resource in intercropping, in analogy with LER, ranged from 0.87 to 1.16, and ΔWU, the relative departure of actual water use in intercropping from expected use, ranged from −13.7% to 19.8%, indicating variability in the effect of intercropping on water use efficiency. Plastic film in maize increased yield and water use efficiency, but did not significantly affect LER or WER, indicating that intercropping advantage was not affected by plastic film mulch, and the advantages of film mulch were conserved under intercropping. A cropping system of 4 rows maize with 4 rows peas, with 30 cm between maize rows and 20 cm between pea rows, was superior in yield and water use efficiency to a system with 2 rows maize and 4 rows of pea with 40 cm between maize rows and 20 cm between pea rows. It is concluded that intercropping of maize and pea enhances land use efficiency compared to growing them as sole crops. Film mulch saves water in sole crops as well as intercrops.

1. Introduction

Intercropping is common in semi-arid areas because of high yields and high resource use efficiencies (Gao et al., 2009; Li et al., 2001; Mandal et al., 1996; Willey and Reddy, 1981). Over the last decades, maize/wheat intercropping has been widely practiced in Gansu Province, northwest China. In this system, spring maize is the dominant crop with a long growing season (around 24 weeks). The high yields and resource use efficiencies of this system have been well documented (Li et al., 2001, 2003). It had been reported, however, that wheat consumes more water than other crops (Sun et al., 2006). A maize/wheat intercropping system thus requires 8–9 irrigations with a total amount of irrigation water of about 630 mm (Hu et al., 2010). Responding to water shortages in the region, some local governments, e.g. in Wuwei city, have reduced the allocation of irrigation water to farmers, rendering the maize/wheat system impracticable, and prompting the development of high yielding crop systems with lower water demand. One of the systems that have emerged under water constraint is the intercropping of maize and pea. From 2005 onwards, local farmers rapidly developed maize/pea intercropping; for example, around 13,000 ha in Wuwei.

Peas are sown in late March, approximately 1 month before the maize, and harvested in early July, approximately 3 months before the harvest of maize. The co-growth period of peas and maize is 10–11 weeks. During this phase, the maize plants gradually grow above the peas, capturing an ever greater proportion of the available light, water and nutrient resources. Row arrangements of maize/pea intercropping systems commonly used are: (i) 2 rows of maize and 4 rows of pea, and (ii) 4 rows of maize and 4 rows of pea, with different row distances (Fig. 1). In these new intercrop systems, the irrigation frequency is reduced by about 50% compared to what was previously used in maize/wheat, in adaptation to the reduced water allocation by authorities.

Field pea is known as a drought-tolerant cash crop. It shows potential for intercropping with maize to obtain both a high productivity and a low water use (Siddique et al., 2001). There is,

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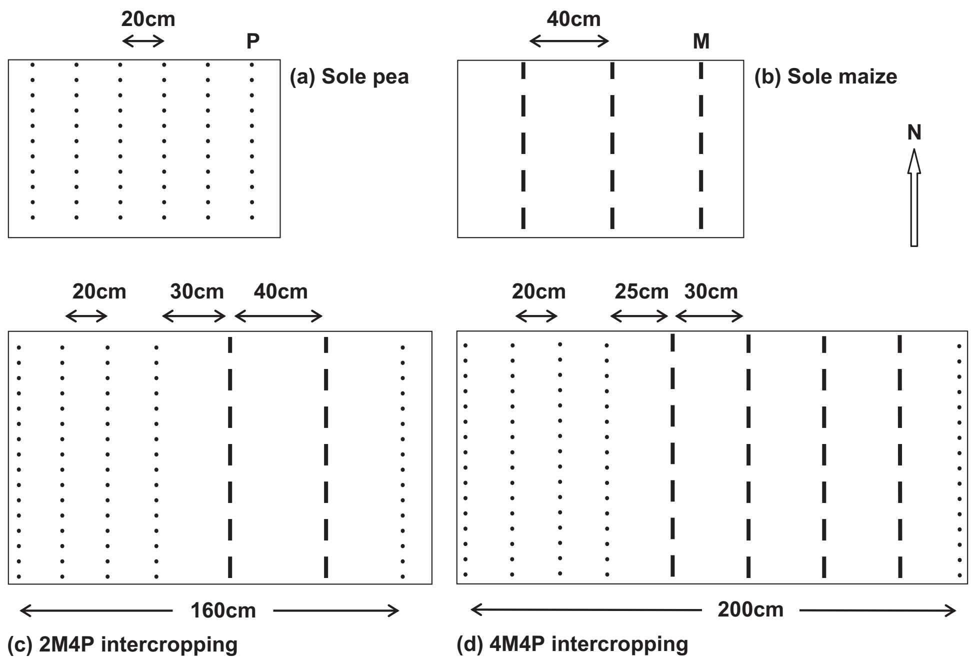

Fig. 1. Row arrangements of pea and maize in field experiments: (a) sole pea; (b) sole maize; (c) maize/pea intercrop (2M4P); (d) maize/pea intercrop (4M4P). M indicates maize row and P pea row. N means North.

however, a lack of the scientific underpinning of the gap between potential and actual productivity of this intercropping system, how much water can be saved, and how the system could be further improved.

Plastic film cover is one of the common practices to reduce evaporation and raise productivity under water constraint (Fisher, 1995). Plastic film directly affects the microclimate of the plant by modifying the radiation budget of the surface and decreasing the soil water loss (Liakatas et al., 1986). Film mulching increases crop yields both quantitatively and qualitatively (Ramakrishna et al., 2006) and enhances water use efficiency (WUE) (Liu et al., 2009; Zhao et al., 2012). There is however very little information on the effect of plastic mulch on water use and productivity in intercrops, and it is unknown how row spacing and plastic film affect the spatial distribution of water and productivity across the rows in maize/pea intercrop.

Row arrangement is commonly used to optimize productivity and resource use efficiency in intercrops (Zhang et al., 2007). Changing the width of crop strips affects the proportion of border rows. Border rows often have increased yield due to reduced competition from the companion crops which usually has a different resource acquisition strategy in space and time (Zhang et al., 2008).

Based on the above questions, the objectives of this work are to (a) quantify land use efficiency and the effects of plastic film cover in maize and field pea intercrop; (b) quantify water use efficiencies in different intercrop arrangements compared with the monocultures; and (c) to explore the spatial and temporal water depletion and its effects on the water use efficiency.

2. Materials and methods

2.1. Site description

Field experiments were conducted in 2010 and 2011 in Wuwei, Gansu Province, northwest China (38°37′N, 102°40′E). The site is 1504 m above sea level and has an annual average temperature of 7.7 °C. The frost-free period is 170–180 days. Total average solar radiation is 6 GJ m^{-2} y^{-1}. The area is arid with an average annual rainfall of 150 mm and a potential water pan evaporation of 2021 mm. The average heat sum, expressed in degree-days above 0 and 10 °C, was 3646 °Cd and 3149 °Cd, respectively. The rainfall during the whole growing season from the sowing of pea to the harvest of maize amounted to 93 mm in 2010 and 212 mm in 2011, 52 mm (2010) and 66 mm (2011) of which fell within the co-growth period (from the sowing of maize to the harvest of pea).

The soil is an Aridisol (serozem). Physical and chemical characteristics are: a pH (water) of 8.0, total N of 0.86 g kg^{-1}, available P (Olsen-P) of 23.03 mg kg^{-1}, available K of 121.92 mg kg^{-1} and organic matter content of 15.96 g kg^{-1} in the top soil layer (0–20 cm). Soil bulk density was determined in six layers of 20 cm soil thickness using the cutting ring method (Blake and Hartge, 1986): 1.42 g cm^{-3} (0–20 cm), 1.42 g cm^{-3} (20–40 cm), 1.42 g cm^{-3} (40–60 cm), 1.30 g cm^{-3} (60–80 cm), 1.25 g cm^{-3} (80–100 cm), and 1.20 g cm^{-3} (100–120 cm). Bulk density was used in the gravimetric measurement of soil moisture.

2.2. Experimental design

Experiments were conducted in 2010 and 2011 with 4 replicates in a randomized block design, comprising 3 monocultures and 4 intercrops. The three monocultures were: (i) sole maize without film cover, (ii) sole maize with film cover and (iii) sole field pea. The four intercrop systems were: (i) 2 rows of maize without film cover and 4 rows of field pea (2M4P−), (ii) 2 rows of maize with film cover and 4 rows of field pea (2M4P+), (iii) 4 rows of maize without film cover and 4 rows of field pea (4M4P−), and (iv) 4 rows of maize with film cover and 4 rows of pea (4M4P+). The row spacing of peas was 20 cm in both monoculture and intercrop, while the row spacing of maize was 40 cm in monoculture and 2M4P, and 30 cm in 4M4P (Fig. 1). The distance between adjacent maize and pea rows was 30 cm in the 2M4P and 25 cm in the 4M4P intercrop. Relative densities (i.e. the density in intercrop as a proportion of the density in monocrop) of maize and pea were 0.5 for both species in the 2M4P system, and 0.8 for maize and 0.4 for pea in the 4M4P system (Table 1). Thus, the 2M4P system is a replacement design while