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As the level of crop productivity increases: Is there a role for intercropping in smallholder agriculture

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ABSTRACT

Intercropping is a common practice in low productivity (low input–low output) small-scale farming systems. However, as the level of productivity increases due to technological improvements whether intercropping – compared to sole cropping – remains the most productive and resource efficient cropping system is not well understood. Here we hypothesize that inter-crops outperform sole crops at low levels of resource availability because of improved resource capture and resource use efficiency; and answered whether this advantage decreases with increasing levels of resource availability. The performance of three cropping systems i.e. maize intercropped with navy bean, sole maize and sole navy bean were evaluated at three levels of resource input i.e. a low water/nitrogen (low W/N), a medium water/nitrogen (medium W/N), and a high water/nitrogen (high W/N), in three independent experiments, conducted over two consecutive years. The performance of the cropping systems was evaluated in terms of land equivalent ratios (LER), total grain yield, protein and energy productions as well as resource (water, nitrogen, and solar radiation) capture and use efficiency. Our results indicate that maize productivity (grain yield, protein and energy productions) was not significantly affected by the intercrop at any level of resource availability. However, irrespective of the level of resource input, intercropping significantly reduced the productivity of navy bean. The advantage of the intercropping, in terms of LER, tended to decrease with increasing the level of water and nitrogen supply i.e. decreased from 28% to 6% for above ground biomass, from 40% to 7% for grain yield, from 41% to 0.3% for protein production and from 40% to 9.2% for energy production. Intercropping was therefore more efficient in terms of LER under low W/N than under high W/N conditions. The LER was directly related to improved capture of nitrogen and to higher water use efficiency. Here we conclude that in terms of LER, intercropping systems are more resource efficient and suitable for lower productivity environments. As more productive technologies are adopted by smallholder farmers, agricultural development projects and extension services need to consider under what conditions sole cropping become a more productive system.

1. Introduction

Intercropping – the simultaneous growth of two or more crop on the same area of land – has been a common intensification practice by low input–low output, small-scale farmers. It has been suggested that intercropping increases land productivity through improved resource capture and use efficiency (Morris and Garrity, 1993). However, as farmers improve their agronomic practice and access improved seeds, fertilizers and herbicides, whether intercropping remains more productive than sole cropping systems, remains unclear.

Reports on maize (*Zea mays* L) haricot bean (*Phaseolus vulgaris* L)/soybean (*Glycine max* L) intercrops (Pilbeam et al., 1994; Tsubo et al., 2004; Ogindo and Walker, 2005; Vahdettin et al., 2006; Ouda et al., 2007; Belay et al., 2009; Echarte et al., 2011) show that, in general, intercropped crops have higher LER values under low productivity environments, i.e. in water limited conditions. However, whether the better performance of intercropped crops was driven by an improved capture or use efficiency of available resources is not clear.

Morris and Garrity (1993) showed that intercropped systems had slightly higher values of water use and water use efficiencies relative to sole crops. Water capture and water use efficiency in intercrops were as high as 7% and 99%, and as low as −6% and 18%, when compared to sole crops, respectively. Kanton and Dennett (2004) found larger values of water use efficiency in intercrops

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compared to sole crops in additive series arrangements. According to Willey (1990), the differences in water capture might be explained by the different root distributions from the two crops exploring different volumes of the soil profile.

Other reports (Hauggaard-Nielsen et al., 2006; Musa et al., 2010; Li et al., 2011c; Lithourgidis et al., 2011) also indicated improved N capture by cereal–legume intercropping systems compared to cereal–cereal intercropping systems. This is probably as a result of complementary use of N by the component crops (Bedoussac and Justes, 2010).

When other resources are not limiting (e.g. N and water) factors, photosynthetically active radiation (PAR, 0.4–0.7 μm wavelength) is the most important resource for crop growth and development in intercropping systems with crops of different heights (Watiki et al., 1993). Several studies indicate improved radiation interception and utilization in intercrops compared to sole crops (Reddy and Willey, 1981; Natarajan and Willey, 1986; Pilbeam et al., 1994; Szumigalski and Van Acker, 2008; Gao et al., 2010). However, the opposite was also observed (Zhang et al., 2008).

It has been proposed that intercropping systems capture and utilize more water, nitrogen and light than sole crops. However, as the level of resource availability of the environment increases, the question of whether intercropping remains the most productive and resource efficient cropping system is not known. The objective of this work was to test whether in terms of land equivalent ratio (LER), (i) inter-crops outperform sole crops at low levels of resource availability because of improved resource capture and resource use efficiency; and (ii) to answer whether this advantage decreases with increasing levels of resource availability.

2. Materials and methods

2.1. Experimental condition

Field experiments were conducted during the summers of 2011/2012 and 2012/2013 at the Gatton Research Station (152°34′E and 27°54′S), the University of Queensland, Australia. Daily in-crop rainfall (ICR), temperature and solar radiation during the 2011/2012 and 2012/2013 seasons are presented in Fig. 1. Seasonal conditions were different between 2011/2012 and 2012/2013, particularly in the amount of total ICR i.e. 284 mm in the first season, and 500 mm in the second season. The earlier planting during the first season meant that the 2011/2012 season was slightly cooler and the crop was exposed to lower levels of incoming radiation. Average minimum and maximum temperatures were 15 °C and 28 °C in the first season and 18 °C and 31 °C in the second season; while the average incoming solar radiation was 18 MJ m^{-2} in the first season and 25 MJ m^{-2} in the second season. Compared to the long-term climate records for Gatton, Queensland, Australia, daily mean solar radiation and total ICR were lower than the long-term averages (i.e. 19 MJ m^{-2} and 339 mm) for the 2011/2012 season

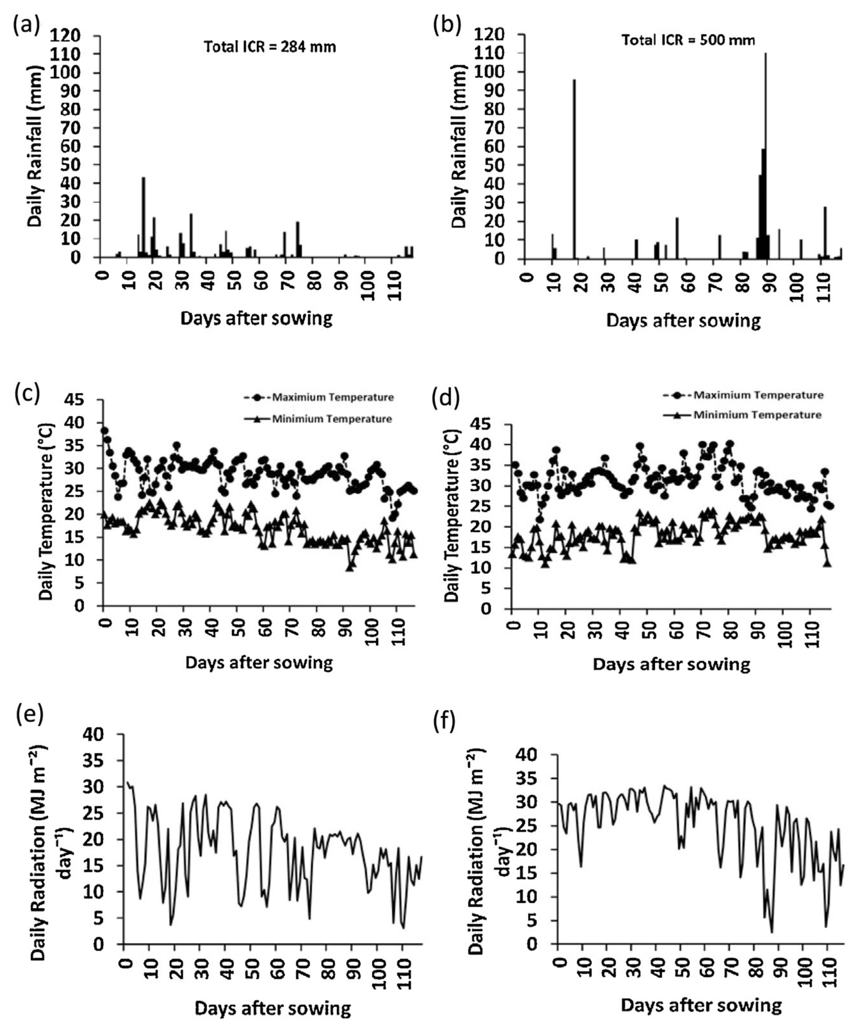

Fig. 1. Daily in-crop rainfall, ICR (a and b), maximum and minimum temperature (c and d) and solar radiation (e and f) from sowing to physiological maturity of maize during 2011/2012 (a, c and e) and 2012/2013 (b, d and f) at Gatton, Australia.