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Above- and below-ground interspecific interaction in intercropped maize and potato: A field study using the 'target' technique

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ABSTRACT

The association of maize (*Zea mays* L.) and potatoes (*Solanum tuberosum* L.) is an overyielding multi-cropping system. However, knowledge on specific interactions in field conditions, especially below-ground interactions, is deficient. To evaluate the nature and strength of interspecific interactions between maize and potatoes, field and pot experiments were conducted using the 'target' technique, with three interaction models: no interaction (NI), below-ground interaction (BI) and full (both above- and below-ground) interaction (FI). Plants were sampled at flowering and harvest periods to measure biomass and calculate the log response ratio (lnRR), root:shoot ratio and land equivalent ratio (LER).

In the field experiment, the lnRR value of both BI and FI treatments for potatoes was > 0, whereas for maize it was < 0. This result accorded with differences in biomass, yield, Harvest Index and root:shoot ratio between the two treatments for both crops. Results showed that maize was subjected to competition (negative interaction), while potatoes obtained facilitation (positive interaction) when they were intercropped. In addition, after flowering there were no significant differences between BI and FI treatments in terms of biomass, lnRR, yield and LER for the two crops. Thus, compared with above-ground interaction, below-ground interaction (i.e. root competition for maize and root facilitation for potatoes) plays a more important role for crop growth and intercropping advantages.

In the pot experiment, however, the lnRR values of both BI and FI treatments were < 0 for both crops, so potatoes did not obtain a net profit from maize. However, the competitive capability of potatoes were significantly greater than maize when they were intercropped, which is consistent with results from the field experiment. Similarly, there were no significant differences between BI and FI treatments in terms of biomass, lnRR, root:shoot ratio and LER for the two crops.

In summary, our study suggests that the root facilitation produced by maize for potatoes is a mechanism for overyielding in the maize–potato intercropping system. The potential of this system merits further research.

1. Introduction

In multi-cropping systems, the use and management of interspecific interactions can enhance crop productivity and produce yield advantages (Zhang and Li, 2003). When crops are planted together, both negative interaction (competition) and positive interaction (facilitation) can occur simultaneously (Callaway and Walker, 1997; Mariotti et al., 2009). Competition restrains crop growth by sharing the limited resources or allelopathy (Gentle and Duggin, 1997); whereas facilitation promotes crop performance by improving the micro-environment for utilizing resources (Brooker et al., 2008). Therefore, when we increase facilitation and decrease competition between crops, multi-cropping systems can use environmental resources more effectively and can reduce costs, which improves the sustainability of crop production. However, most previous work on interspecific interaction between crops focused on legume-based cropping systems (Snaydon, 1982; Gunes et al., 2007; Mariotti et al., 2009; Zhang et al., 2011a,b) and cereal–cereal systems (Zhang and Li, 2003; Li et al., 2011). Knowledge is lacking on interspecific interaction in cereal and solanaceae intercropping systems, such as the combination of maize and potatoes.

The soil–air interface creates a spatial division between above- and below-ground interspecific interactions. Crop shoots acquire light and CO_2 above-ground, whereas roots absorb water and nutrients below-ground (McPhee and Aarssen, 2001). However, increasing evidence from studies on multi-cropping systems indicate that root interactions are more important than shoot interactions for determining crop productivity and intercropping advantages (Martin and Snaydon, 1982; Ong et al., 1991;

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Tofinga et al., 1993; Zhang and Li, 2003; Thorsted et al., 2006; Walker and King, 2009). Furthermore, due to increasingly important environmental issues, such as soil erosion (Montgomery, 2007), acidification (Guo et al., 2010) and drought (Zhao and Running, 2010), soil resources (i.e. nutrients, moisture and texture) are gradually becoming depleted. Consequently, the productivity of cultivated land will primarily depend on the availability of soil resources. Therefore, understanding interspecific below-ground interactions between crops is crucial to promote sustainable grain production (Casper and Jackson, 1997; Zhang et al., 2002; Zhang and Li, 2003; Gomiero et al., 2011; Zhang et al., 2011a,b). However, field experiments have given little attention to root interactions, due to technical difficulties. Indeed, the methods used in current studies may fail to fully explore the nature of root interactions between crops.

Generally, the 'divided pot', 'target' and 'row' techniques are the main methods to separate above- and below-ground interactions between plants in the field (McPhee and Aarssen, 2001). The 'row' technique proposed by Schreiber (1967) can simulate the field conditions in which crops are grown in rows, and is thus used by most intercropping studies (Tofinga et al., 1993; McPhee and Aarssen, 2001; Zhang et al., 2002; Thorsted et al., 2006). However, the aerial partitions in a 'row' design affect community micro-environment, such as temperature and light orientation in the canopy (McPhee and Aarssen, 2001). This can be confused with the effects of below-ground interaction; while the vertical partitions below-ground restrict root exploration of soil interstices (Semchenko et al., 2008; Prusinkiewicz and Barbier De Reuille, 2010). In addition, because the 'row' technique provides a population environment for individual crop growth, intraspecific competition in the row affects interspecific competition in adjacent row(s) (Schreiber, 1967; McPhee and Aarssen, 2001; Mariotti et al., 2009). Therefore, this method cannot meet the need to explore the nature of root interaction between crops. Obviously, an individual growth environment for crops is useful to explore below-ground interaction between field crops. The 'target' technique, originally proposed by Clements et al. (1929) and usually used for the study of natural vegetation, could overcome these issues. However, this design was seldom used in field studies of root interactions between crops.

As a cereal–solanaceae intercropping system, the association of maize and potato is overyielding in many regions of the world (Midmore et al., 1988; Manrique, 1996; Ebwongu et al., 2001a; Al-Dalain, 2009; He et al., 2010). The two species differ in growth forms and physiological parameters. Thus, resources are used in a complementary fashion, in both time and space, due to niche partitioning. Moreover, this system can optimize the utilization of micro-climatic resources, and can thus promote crop growth. For example, Sharaiha and Battikhi (2002) found that intercropped potatoes have cooler micro-environments than monocultured ones, with lower soil and air temperatures, which benefit the growth and tuber development of potatoes. Furthermore, the combination of maize and potatoes can ecologically control crop diseases and pests, such as the late blight of potato and northern leaf blight of maize (He et al., 2010), and the aphids and leafhoppers of potatoes (Ebwongu et al., 2001b). In order to further improve and optimize the productivity of this intercropping system, it is crucial to understand the interspecific interactions between the two crops. However, few studies have focused on the mutual shading effect (i.e. above-ground interaction) between maize and potatoes (Midmore et al., 1988; Vander Zaag and Demagante, 1990), and only one growth chamber study (Mushagalusa et al., 2008) investigated the effects of shoot and root competition on crop productivity. Therefore, knowledge on interactions in the field, especially below-ground interactions, is deficient.

In this study, we used the 'target' technique to create an individual growth environment for crop growth in the field, and conducted a field and a pot experiment with three interaction models: no interaction (NI), below-ground interaction (BI) and above- and below-ground interaction (FI). We separated above-ground interaction by neighbour tiebacks (Twolan-Strutt and Keddy, 1996; Cahill, 2002) in the BI treatment. After plants were harvested at the flowering and ripe stage, we measured biomass and yield, and calculated the log response ratio (lnRR), root:shoot ratio, land equivalent ratio (LER) and Harvest Index. Our aim was to evaluate the nature and strength of below-ground interaction between maize and potatoes and to compare the relative contribution to productivity of above-ground and below-ground interactions.

2. Materials and methods

2.1. Field experiment

2.1.1. Study site

The field experiment was carried out during March–September 2010. The experimental site was located at the Agricultural Experimental Station, Faculty of Agronomy and Biotechnology, Yunnan Agricultural University (102°2′E, 25°22′N). Altitude is 1930 m above sea level, with a mean annual temperature of 14.7 °C. Mean annual precipitation is 960.0 mm and mainly falls during May–September. The mean solar radiation and frost-free period per year were 2617 h and 301 days, respectively. The field soil is Red soil (Chinese Classification), Typic Hapludult (US Soil Taxonomy) or Ferric Acrisol (WRB Classification). Texture is a silty clay loam, with a typical texture of ~10% sand (2000–60 μm), ~50% silt (60–2 μm) and 40% clay (<2 μm). Typical soil pH is 5.7. The crop preceding the field experiment was spring wheat. At the start of experiments, the soil (0–20 cm depth) contained total N, P and K of 1.4, 3.21 and 4.47 g kg^{-1}, respectively. The available N, P and K were 9.72, 17.0 and 113.6 mg kg^{-1}, respectively. The sowing date was 18 March 2010 for potatoes and 19 May 2010 for maize. Before sowing, fertilizer (N: 150 kg ha^{-1}, P_2O_5: 110 kg ha^{-1}, K_2O: 100 kg ha^{-1}) were evenly mixed into the soil within the 0–20 cm layer. During the experimental period, the plot area was weeded by hand, as required.

2.2. Experimental design

The semi-compact maize (Yunrei-6) and shade-tolerant potato (Hui-2) were chosen for intercropping studies. This cultivar combination is widely used in Yunnan agriculture. Each crop was grown in the field with three interaction models: no interaction (NI), below-ground interaction (BI) and full interaction (FI) (Fig. 1A). For both crops, the six treatments with three replicates were placed randomly within three blocks. Each treatment had a 8.80 m × 2.65 m plot.

The 'target' technique of Clements et al. (1929) allows an individual growth environment for the target crop without confusion with intraspecific competition, as occurs in the 'row' technique. This is because individual 'target' plants are fully surrounded by the 'neighbour' plants, and it also avoids the effects of above- and below-ground partitions in 'row' design. Fig. 1A illustrates the 'target' design in this study. In below-ground interaction (BI) and full interaction (FI) treatments, experimental units were structured with one target crop in the centre and two neighbours at sides, which simulate the crop arrangement in strip intercropping. In the no interaction (NI) treatment, only one target crop grew without any neighbour. In order to achieve a realistic light environment according to the needs of each treatment, three plants in an experimental unit were arranged in north–south directions for the BI treatment and east–west directions for the FI treatment. To reduce the effects between experimental units, the spacing between