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Understanding interactions between cropping pattern, maize cultivar and the local environment in strip-intercropping systems

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ABSTRACT

Strip-intercropping systems combine the possibility to increase productivity and resource-use-efficiency with the facilitation to accommodate machinery. In strip-intercropping systems with maize, competition for light strongly influences the total productivity. Therefore, we studied plant growth and yield formation in maize grown in strips with a neighboring, shorter crop (e.g. bush bean) over three growing seasons in the North China Plain (NCP) with irrigation and over four growing seasons in south-western Germany without irrigation. The chosen locations represented different latitudes, weather, and management conditions. Based on these data, interactions between the local environment, mainly radiation and water availability, and the planted maize cultivars were investigated. Further, a light partitioning model was used to study the effect of strip width, maize canopy height and leaf area index (LAI), latitude, and sky conditions on the light availability across the strip of bush bean over the co-growing period with maize. Experimental results showed an increase of maize yield in border rows in years with sufficient water supply. On average, maize yields calculated for strips consisting of 18 to four rows showed an increase by 3 to 12% at the German and 5 to 24% at the Chinese sites, respectively. Among the three cultivars included in this study, yield in border rows increased mainly by a larger number of kernels per plant. Those were achieved by a larger number of ears per plant in the German cultivars and by larger number of kernels per ear in the Chinese cultivar, respectively. Simulations of the light availability across the strip of the neighboring, shorter bush bean crop indicated that increasing the strip width might only reduce shading in the border rows when the bush bean is grown at lower latitudes under a high fraction of direct radiation. When grown at higher latitudes, the selection of a maize cultivar with reduced height and LAI are suitable options to increase the light availability for the shorter crop. However, shade levels in the border rows of the shorter crop remain high at around 25%. For the future improvement of the productivity of strip-intercropping systems, the selection of suitable maize cultivars and shade-tolerant cultivars and species will be decisive.

1. Introduction

Intercropping, or the cultivation of two or more crops simultaneously on the same field is a common practice in low-input, smallholder farming systems in developing countries. An option of intercropping more common in highly modernized agricultural systems is arranging the intercrops in alternating strips (Vandermeer, 1989). The cultivation of two or more crops in strips combines the positive effects of intercropping, such as a higher productivity and resource-use-efficiency (e.g. Willey, 1990; Zhang and Li, 2003), with the facilitation to accommodate machinery. Studies on strip-intercropping of maize and soybean were initiated in US farming systems facing an ongoing mechanization, which challenged growing the two crops in alternating rows or pairs of rows (Pendleton et al., 1963). Decisive for the productivity of both crops are the interspecific interactions in the border rows at the edges of the strips. In general, the dominant crop maize yielded higher in border rows due to a higher radiation interception. On the contrary, yields in the border rows of the subordinate crop soybean

Abbreviations: LAI, leaf area index; TKW, thousand kernel weight; PAR, photosynthetically active radiation; DSSAT, decision support system for agrotechnology transfer; HI, harvest index.

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were reduced by competition for water and nutrients, but mainly because of the decreased light availability (Jurik and Van, 2004). In many cases the higher yields in maize border rows were offset by the decrease in the border rows of soybean yields, e.g., a 20% yield increase in maize and a 20% yield decrease in soybean in four and six rows alternating strips (Pendleton et al., 1963); 26% higher yields of maize and 27% lower yields of soybean in alternating eight rows (West and Griffith, 1992); maize and soybean under irrigated and rainfed conditions showed a 26 and 19% yield increase of maize and a 28 and 22% decrease of soybean yields (Lesoing and Francis, 1999). Other studies showed a total yield advantage with a 20–24% yield increase in maize border rows and only a 10–15% decrease in soybean border rows (Ghaffarzadeh et al., 1994). However, the studies mentioned vary in location, strip width and maize cultivar. Thus, it remains difficult to conclude suggestions for the optimized planting pattern adapted to other locations.

A large variety of narrow strip-intercropping systems, e.g. of wheat-cotton (Zhang et al., 2008), maize-wheat (Li et al., 2001; Knörzer et al., 2011), maize and soybean (Gao et al., 2010), and others including vegetable species (Feike et al., 2010) exist in the North China Plain (NCP). In addition many studies have been conducted about, e.g. interspecific interactions between the intercrops (Li et al., 2001, 2011; Zhang and Li, 2003), radiation-use-efficiency (Gao et al., 2010) and evapotranspiration of the intercrops (Gao et al., 2013). The high interest in intercropping systems in the NCP can be explained by the challenge of increasing yields on limited resources of arable land with less input of irrigation water, fertilizers, and pesticides in the face of the future food security, the severe overuse of inputs and its related environmental problems (Fan et al., 2012; Meng et al., 2012).

The narrow-strip intercropping systems practiced in the NCP showed considerable yield advantages compared with monocropping in numerous studies (e.g. Gao et al., 2010; Li et al., 2001). Gao et al. (2010) showed a total yield increase of 65 and 71% in a system of one and two rows of maize (planted at a higher density in intercropping) alternated with three rows of soybean compared with both crops grown as monocrops.

However, these labor-intense narrow strip-intercropping systems are likely to be challenged by an ongoing shift from rural labor to urban areas with higher income possibilities. The resulting scarcity of manual labor in rural areas led to a steady decrease in intercropping systems as shown recently for a representative area in the NCP by Feike et al. (2012). Growing the crops in wider strips would allow the use of machinery and decrease the need of manual labor. However, the possible yield advantage of maize grown in wider strips has never been studied under the growing conditions in the NCP. The overall productivity will finally depend on the yield increase of maize and the degree of shading promoted by the maize strips to the strip of the subordinate crop. Ghaffarzadeh (1999) emphasized in a summary about strip-intercropping systems in Iowa (USA), that there is a need to study the influence of different maize cultivars on the overall productivity. However, to the best knowledge of the authors, no respective study has been published. Simulations by Munz et al. (2014) with a light partitioning model for strip-intercropping systems indicated that the shading by the maize strips might be reduced by a maize cultivar with reduced plant height and reduced leaf area index (LAI). A crucial aspect hindering the optimization of strip-intercropping systems is the high demand of labor and time to study plant growth, yield formation and the microclimate within strips, and the large number of possible plant arrangements and species combinations. Hence, the use of plant growth models is regarded as crucial in further improving our understanding of the processes that influence the productivity with the aim to identify the optimum plant arrangement for each location (Knörzer et al., 2011; Munz et al., 2014).

Table 1
Sowing, silking and harvest date of maize for the growing seasons in China (2009–2011) and Germany (2009–2012).

Growing season	Sowing date	Silking date	Harvest date
China, 2009	1 May	8 July	15 September
China, 2010	4 May	12 July	15 September
China, 2011	4 May	9 July	21 September
Germany, 2009	24 April	16 July	12 October
Germany, 2010	21 April	24 July	21 October
Germany, 2011	26 April	18 July	18 October
Germany, 2012	27 April	20 July	10 October

Therefore the objectives of this study were to: (i) evaluate plant growth and yield formation of maize strip-intercropped with a shorter subordinate crop under the growing conditions in the NCP and in south-western Germany, two locations that mainly differ in latitude, seasonal water availability (rainfall and irrigation) and temperature; (ii) evaluate the influence of maize on the light availability for the shorter subordinate crop across different locations (latitudes) by changing important parameters, such as the strip width of both crops, and the canopy height and LAI of maize based on a plant growth and a light partitioning model; and (iii) identify parameters for further improvement of strip-intercropping systems with the dominant crop maize.

2. Materials and methods

2.1. Experimental design

Field experiments were conducted in Germany during the growing seasons 2009 to 2012 and in China from 2009 to 2011. In Germany, the experiments were carried out at the experimental station “Ihinger Hof” of the University of Hohenheim in southwestern Germany (48°44′N, 8°55′E; 477 m a. s. l.). In China, experiments were conducted at two different locations in the North China Plain; in 2009, at the CAU Experimental Station in Quzhou (Hebei; 36°52′N, 115°0′E, 37 m a. s. l.) and in 2010 and 2011 at the experimental station of the Institute of Agricultural Sciences in Fangshan, Beijing (Beijing; 39°41′N, 116°8′E, 50 m a. s. l.). According to the World Reference Base (IUSS Working Group WRB, 2007) soils are classified as Calcaric Cambisol (Quzhou and Fangshan), Orthic Luvisol (Ihinger Hof 2009–2011) and Vertic Luvisol (Ihinger Hof 2012), respectively.

In China, the cultivar ‘Xianyu335’ (Tieling Pioneer Seed Research Co., Ltd., Shenyang, China) was sown in the first week of May with a row spacing of 0.6 m and a plant density of 8.3 plants m^{-2} in 2009 and 6 plants m^{-2} in 2010 and 2011. The respective dates of sowing, silking, and harvest for each growing season in China are listed in Table 1. Fertilization of nitrogen (urea)/phosphorus (mono calcium phosphate)/potassium (potassium-chloride) were 200/140/170 kg ha^{-1} in 2009, 80/60/100 kg ha^{-1} in 2010, and 250/60/100 kg ha^{-1} in 2011. The amount of urea applied varied due to large differences of pre-sowing soil mineral nitrogen content among years and locations. In the study area in China, rainfall is concentrated mainly during the summer months and for maize water supply is limited during its early vegetative growth. Hence, during all years maize was irrigated shortly after sowing with 50 mm. Additional irrigation depended on rainfall, and thus varied over the years. The total irrigation amount was 280 mm in 2009, and 50 mm in 2010 and 2011. In 2010, necessary additional irrigation was not possible due to the limited water availability for irrigation. Independent irrigation of each crop was facilitated by parallel dams between the crops of around 30 cm width and 20 cm height.

In Germany, the early-maturing dent-maize (*Zea mays* L.) cultivars ‘Companero’ (Agromais GmbH, Everswinkel, Germany) and