Europ. J. Agronomy 76 (2016) 17–27

Contents lists available at ScienceDirect

European Journal of Agronomy

journal homepage: www.elsevier.com/locate/eja

Yield and yield components of wheat and maize in wheat–maize intercropping in the Netherlands

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ARTICLE INFO

Article history:
Received 15 April 2015
Received in revised form
24 December 2015
Accepted 17 January 2016
Available online 13 February 2016

Keywords:
Europe
Intercrop configurations
Border row effect
LER

ABSTRACT

Intercropping is widely used by smallholder farmers in developing countries, and attracting attention in the context of ecological intensification of agriculture in developed countries. There is little experience with intercropping of food crops in Western Europe. Yields in intercrops depend on planting patterns of the mixed species in interaction with local growing conditions. Here we present data of two years field experimentation on yield and yield components of a wheat–maize intercrop system in different planting configurations in the Netherlands. Treatments included sole crops of wheat (SW) and maize (SM), a replacement intercrop consisting of strips of six wheat rows alternating with two maize rows (6:2WM), as well as subtractive or additive designs, based on skip-row (6:0WM, 0:2WM) and add-row (8:2WM, 6:3WM) configurations. The land equivalent ratio (LER) of intercrops varied from 1.18 to 1.30 in 2013 and from 0.97 to 1.08 in 2014. Wheat grown in the border rows of wheat strips had higher ear number per meter row, greater kernel number per ear, and greater yield per meter row than wheat in inner rows and sole wheat, indicating reduced competition. Wheat in the border rows in the intercrops had, however, reduced thousand kernel weight and harvest index, indicating that competition in border rows intensified over time. Intercropping negatively affected maize biomass and thousand kernel weight, especially in add-row treatments. This study indicates that there is a potential yield benefit for the wheat–maize intercropping system under Western European growing conditions. However, the LER was affected by yearly variation in weather conditions and significantly greater than one in only one of the two years of the study.

1. Introduction

Global grain production has more than doubled in the past half-century due to genetic improvements, application of fertilizers and pesticides, and improved water management (Tilman et al., 2002; Valipour et al., 2015). Yet, the world is projected to need 60–70% more food to feed 9.5 billion people by 2050 (Alexandratos and Bruinsma, 2012), thus further improvement in productivity is crucial for food security in the future (Tilman et al., 2002; Spiertz, 2013). Intercropping is the cultivation of two or more crop species simultaneously in the same field (Vandermeer, 1989), which has potential advantages such as higher overall productivity, better pest and disease control and enhanced ecological services (Malézieux et al., 2009; Lithourgidis et al., 2011a). Intercropping has been used for millennia by smallholder farmers in Asia, Africa and Latin America to increase yields per unit land and exploit species complementarities, and is still widely practiced. Relay intercropping is a special form of intercropping in which two or more crop species overlap only partially in growing period (Vandermeer, 1989). In a relay intercrop, the second crop is sown or planted well after emergence of the first. Usually, the first crop is harvested before the second. Wheat–maize intercropping is an example of a relay system.

Wheat–maize intercropping is practiced in Northwest China, notably Gansu province and Ningxia autonomous region (Li et al., 2001b). In these regions, the thermal time is not sufficient to grow wheat and maize after each other in one growing season as in the North China Plain (south of Beijing), but the temperature sum is sufficient to grow two species with partially overlapping growing periods as a relay intercrop. In the wheat–maize intercrop, wheat is sown in strips of approximately six rows wide in spring and harvested in mid-summer. Empty space is left between the

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http://dx.doi.org/10.1016/j.eja.2016.01.005
1161-0301/

wheat strips to sow maize in the late spring, approximately two to three months before the harvest of wheat. Usually, two maize rows are sown in the empty space. The planting pattern conforms to a replacement design in which the relative densities (density in intercrop/density in sole crop) of the component species sum to one. Maize is harvested approximately two to three months after wheat, depending on local temperature regimes. A relay intercrop enables a longer total growth duration than a sole crop, and the associated greater radiation capture over the whole season tends to increase yields compared to sole crops, even when taking into account that the intercropped species are not covering the field completely (Yu et al., 2015). For instance, Zhang et al. (2008) estimated that wheat and cotton in a winter wheat–spring cotton relay intercrop each intercepted approximately 70% as much radiation as sole crops, explaining the relative yields of each of the species also amounting to values close to 70%. Thus, the whole system outperforms the sole crops. Wang et al. (2015) found that total light interception in wheat–maize intercrop in Inner Mongolia, China, was up to 30% higher than in sole wheat and 10% higher than in sole maize, resulting in land equivalent ratios (LERs) above one.

Strip intercropping has not drawn much attention in developed countries because of the challenge of mechanization. However, given the need for increased agricultural production for food and feed on limited land, and the call for a sustainable intensification of agriculture, the principles of intercropping deserve renewed interest to derive possible options for sustainable intensification of agriculture (Lithourgidis et al., 2011a). Intercropping studies in Europe focus on cereal-legume systems, and the different crops were often sown and harvested simultaneously. For example, different combinations and seed ratios of legumes (common vetch or pea) and cereals (wheat, barley, oat, triticale, or rye) were investigated for exploring higher forage yield and protein concentration mixture in Greece (Lithourgidis et al., 2006; Dhima et al., 2007; Lithourgidis et al., 2007; Lithourgidis et al., 2011b). Nitrogen fixation and acquisition were studied in pea-barley intercrops in Denmark (Hauggaard-Nielsen and Jensen, 2001; Hauggaard-Nielsen et al., 2003; Andersen et al., 2005; Ghaley, 2005) and in France (Corre-Hellou et al., 2006). Some other examples refer to intercropping for grain production in organic farming, e.g., wheat–bean intercrop in the United Kingdom (Bulson et al., 1997), oat-pea intercrop in Finland (Kontturi et al., 2011), and cereals (wheat, barley, oat or triticale) intercropped with pea in Lithuania (Arlauskienė et al., 2011). As the crops in these systems were generally harvested simultaneously, mechanical separation after harvest is needed to make the system suitable for mechanization (Bulson et al., 1997). An analysis of 58 European field experiments revealed that cereal-legume intercrops had higher gross biomass and grain yield (0.33 vs 0.27 kg m^{-2}), as well as improved abiotic nitrogen fixation and higher grain protein concentration (11.1 vs 9.8%) than cereal sole crops (Bedoussac et al., 2015).

There is currently no information in the literature on the productivity under European growing conditions of an intercrop of a C3 cereal with a C4 cereal. Here, we study the wheat–maize intercrop system to determine whether growing such a system is at all attractive under European conditions, and to determine the effect of planting patterns. We pay particular attention to the performance of border rows of the wheat strips as these experience no competition during their early growth and may be highly productive as a result, due to, e.g., strong tillering and gap filling responses (Li et al., 2001b; Zhang et al., 2007). Furthermore, we quantify yield components because these provide insight in the strength of early vs late competition. In wheat, for instance, early competition will affect tillering, while late competition will affect kernel filling. Thus, yield components can help to diagnose mechanisms underlying system performance and suggest options for system improvement.

The aim of this study was (1) to quantify the yield and yield components of wheat and maize in different configurations under potential growing conditions in Western Europe, and (2) to understand how border rows and inner rows of wheat and maize contributed to productivity in different wheat–maize intercropping configurations. Care was taken to avoid drought or nutrient stress and to control pests, diseases and weeds, therefore the growing conditions may be considered near potential (van Ittersum and Rabbinge, 1997). Three hypotheses were formulated: (1) we assume that the principles that govern the productivity of intercrops under Western European conditions are similar to those determining demonstrated high productivity under Chinese conditions; hence we expect a LER greater than one. (2) We hypothesize that the land use advantage of intercropping mostly results from enhanced resource capture and yield in border rows. We also tested systems from which one of the crop species was entirely omitted (skip-row treatment) to measure the maximum border row effect, defined as the difference in yield per plant (operationally: per meter row) in inner and border rows of the wheat strip. (3) Wheat–maize intercropping is characterized by partial temporal overlap of the growth periods of the two species. As a result of this, the species are not fully competing for resources, and we hypothesize that resource capture and yield may be increased by increasing densities of one or both of the component species beyond simple replacement, in order to achieve maximum gap filling.

2. Materials and methods

2.1. Experimental set up

The experiments were designed to contrast intercrops with sole crops, and to quantify the border row effects. There were seven treatments: sole crops of wheat (SW) and maize (SM), replacement intercrop (6:2WM), skip-row designs (6:0WM, 0:2WM), and add-row designs (8:2WM, 6:3WM) (Table 1 and Fig. 1). Sole crops were sown according to local practice: 250 plant m^{-2} for wheat and 10 plants m^{-2} for maize. Row distance was 12.5 cm in wheat and 75 cm in maize. In the replacement design, one of every three maize rows was replaced by six rows of wheat, thus the relative density (intercrop relative to sole crop) of maize was 2/3, and the relative density of wheat was 1/3. Skip-row treatments were sole crops in which some rows were skipped, as if the companion crop was omitted from an intercrop, leaving only one of the species. These treatments allowed identifying the maximum border row effect. Add-row treatments were included to test the hypothesis that the relaxation of competition in an intercrop as compared to sole crops could result in some resource "leakage", i.e., resources not being fully intercepted and absorbed, e.g., radiation being lost on the soil, while increasing densities beyond replacement could remedy this leakage and achieve greater yield.

2.2. Experimental site and field management

Field experiments were conducted in 2013 and 2014 at the Wageningen University Farm in Wageningen, the Netherlands (51°59′20″N, 5°39′16″E). Soil was sandy with 3.1% organic matter and a C/N ratio in the organic matter of 14. Climate in the region is oceanic temperate (Table 2). In 2013, spring wheat was sown on 21 March and harvested on 20 August, while maize was sown on 14 May and harvested on 16 October. In 2014, spring wheat was sown on 13 March and harvested on 4 August, while maize was sown on 7 May and harvested on 23 September (Fig. 2). We used the wheat variety "Tybalt" and the maize variety "Atrium". A randomized complete block design with six (2013) and four (2014) replicates was used. Plot size was 9.75 m width by 22.5 m length in