Agricultural Systems 166 (2018) 135–151

Contents lists available at ScienceDirect

Agricultural Systems

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

Effects of temperate agroforestry on yield and quality of different arable intercrops

Pardon P.[a,b,c,*], Reubens B.[c], Mertens J.[a], Verheyen K.[a], De Frenne P.[a,b], De Smet G.[c], Van Waes C.[c], Reheul D.[b]

[a] Department of Environment, Ghent University, Geraardsbergsesteenweg 267, 9090 Gontrode, Belgium
[b] Department of Plants and Crops, Ghent University, Coupure Links 653, 9000 Ghent, Belgium
[c] Flanders Research Institute for Agriculture, Fisheries and Food, Burgemeester Van Gansberghelaan 109, 9820 Merelbeke, Belgium

ARTICLE INFO

Keywords:
Alley cropping
Maize
Potato
Winter cereals
Poplar
Mixed farming

ABSTRACT

Agroforestry systems (AFS) are considered to be a sustainable agricultural practice, as they deliver a wide range of ecosystem services (ES) while maintaining (agricultural) primary production. To optimize the productivity of AFS, the recommendation is to use well adapted tree-crop combinations, thereby limiting competition for resources and maximizing synergies. However, yield and quality data on arable crops in temperate AFS are scarce, in particular for AFS with a mature tree component. Here we assessed the influence of tree rows of contrasting age on yield and quality of key western European arable crops. We focused on (forage) maize, potato, winter wheat and winter barley during three consecutive years (2015–2017) on a set of 16 arable agroforestry fields in Belgium comprising 6 young (2–7 year old) alley cropping fields and 10 fields bordered by a row of deciduous trees of moderate to older age (15–48 years old). Both tree age and crop type were key determinants of yield and quality of the investigated arable crops. While effects on crop yield were limited for all crops near young tree rows, substantial yield reductions were observed near mature trees, in particular for maize and potato (both summer crops). Effects on crop quality were limited for all crops under study, with substantial effects only arising near the oldest tree rows. To optimize the provisioning service of AFS, the cultivation of winter cereals may be advisable over maize and potato towards the end of the rotation of an AFS. In addition, poplar trees should be harvested when they reach their target diameter for industrial processing. If tree rows are preserved for the delivery of other ES, however, substantial impacts on crop yield and quality should be taken into account.

1. Introduction

In temperate regions, the concept of agroforestry is receiving renewed attention (Borremans et al., 2016; Jose et al., 2004; Nair, 2007; Quinkenstein et al., 2009) because it is considered to be a more sustainable agricultural practice than conventional western European agricultural methods. Agroforestry systems (AFS) combine plant production with environmental enhancement and the delivery of ecosystem services (ES) such as carbon sequestration and erosion control (Smith et al., 2012; Torralba et al., 2016). In particular, the practice of alley cropping may offer a promising land use alternative (Quinkenstein et al., 2009). In this type of AFS, trees are planted in rows across the field. As such, the trees can efficiently be combined with the use of modern farming techniques and machinery for the cultivation of agricultural crops in the intercropping zone between the tree alleys (Nerlich et al., 2013; Quinkenstein et al., 2009; Tsonkova et al., 2012).

The study of silvoarable AFS has revealed the existence of multiple potential interactions between trees and intercrops, affecting the availability of resources such as light (Artru et al., 2017; Lin, 2010; Smith et al., 2012), water (Gillespie et al., 2000; Jose et al., 2004), soil organic matter, and nutrient availability (Cardinael et al., 2015a; Pardon et al., 2017). The occurrence and magnitude of these interactions appear to be strongly linked to the design and management of the AFS, the prevailing environmental conditions (climate, soil type, etc.) and the in-field location (Artru et al., 2017; Jose et al., 2008; Reynolds et al., 2007). This variation in growing conditions, both among and within AFS, may in turn affect the yield and development of the cultivated intercrops.

In most parts of western Europe, maize (*Zea mays* L.), potato (*Solanum tuberosum* L.), wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) are the most frequently cultivated arable crops (FAO, 2018; Leff et al., 2004). These crops may exhibit considerable

* Corresponding author at: Department of Environment, Ghent University, Geraardsbergsesteenweg 267, 9090 Gontrode, Belgium.
E-mail address: paul.pardon@ugent.be (P. Pardon).

https://doi.org/10.1016/j.agsy.2018.08.008
Received 4 June 2018; Received in revised form 17 August 2018; Accepted 17 August 2018

variation in the resources needed, both in space (e.g., rooting depth, leaf area index) and in time (e.g., phenology, time to maturity). As a result, not all of them are equally well adapted for use as an intercrop in AFS. But actual quantitative data about the performance (yield and quality) of these crops in temperate silvoarable (alley cropping) systems is limited (Chauhan et al., 2012; Gillespie et al., 2000; Jose et al., 2008; Luedeling et al., 2016; Tsonkova et al., 2012). This is especially the case for AFS with a mature tree component. To address this research gap, we here empirically assessed the yield and quality of two summer crops (maize, potato) and two winter crops (winter wheat, winter barley) in AFS as function of the distance to the deciduous tree rows on an extended set of 16 silvoarable agroforestry fields in temperate Europe (Belgium). We hypothesized i) a reduced yield and ii) altered quality of the intercrop in the immediate vicinity of the tree rows. We furthermore expected that the magnitude of the observed effects and their extent into the field is dependent on iii) the crop type and iv) size class of the tree rows.

2. Material and methods

2.1. Study sites

Two AFS were studied to analyze the effects of a tree component of varying size on the yield and quality of intercrops in arable alley cropping fields (Table 1, Fig. 1). Due to a lack of mature arable alley cropping systems in Belgium, a set of 10 arable fields bordered by a row of high-pruned poplar trees of moderate to older age (15–48 years old) was selected as a proxy. These fields are referred to below as "boundary planted fields" (see Nair et al., 2009; Torquebiau, 2000; Young, 1989). The selected fields were bordered by a tree row along their longest edges with part of the edge without trees. The treeless part of the field creates a reference situation to isolate the tree effect from effects caused by the grassy field margin or other edge effects related to slight differences in fertilization, tillage, etc. ("control zone") (Fig. 1a). The tree rows were oriented (roughly) north-south to limit differences in light availability between fields located on the eastern and western side of the tree rows. These boundary planted fields were grouped into two size classes. The size class denoted as "fields with middle-aged trees" comprised the fields bordered by a row of trees with a circumference larger than 90 cm (diameter at breast height [DBH] of 28.6 cm) and smaller than 200 cm (DBH of 63.7 cm), which is commonly considered to be the maximum diameter for optimal industrial processing (Oldenburger, 2008).The size class denoted as "fields with long-standing trees" comprised the fields with the oldest tree rows in the dataset with a circumference larger than 200 cm (DBH $>$ 63.7 cm). Although these trees exceed the economically optimal harvest size, they are assumed to be beneficial for several ES (e.g., biodiversity, landscape, etc.). In addition, six young alley cropping fields (2 to 7 years old) were selected to investigate the effect of a recently established tree component. On each of the young alley cropping fields a minimum of two tree rows was present. If more than two rows were present, the two adjacent tree rows with the highest expected uniformity in terms of topography, soil conditions, etc. in the intercropping zone were selected for sampling and analysis. All fields were located in Belgium, with a mean annual temperature of 9.7 °C and mean annual precipitation of 828 mm (Grechka et al., 2016).

2.2. Field management

All fields were subject to a conventional arable rotation. Crops were fertilized according to their nutrient requirements (Vandendriessche et al., 1996; VLM, 2014) with animal manure and mineral fertilizers and in accordance with governmental regulations (SPW, 2014; VLM, 2014). Straw of winter cereals was removed after harvest. Soils were tilled, or deep-ripped in case of Vollezele, and the crop residues were incorporated into the soil. During the winter, cover crops (mainly white mustard (*Sinapis alba* L.) and perennial and Italian ryegrass (*Lolium perenne* L. and *Lolium multiflorum* Lam.)) were applied.

2.3. Crop yield

On each of the boundary planted fields, three and two transects were installed perpendicular to the tree row and to the treeless border, respectively (Fig. 1a). In each transect, five sampling plots were marked, the center of which was located at distances 2.5 ("A"), 5 ("B"), 10 ("C"), 20 ("D") and 30 m ("E") away from the tree row/treeless field edge. On the young alley cropping fields, three transects were laid out between and perpendicular to both selected tree rows (Fig. 1b). In each transect, six sampling plots were marked, the center of which was located at distances 2.5 ("F"), 5 ("G") and 12 m ("H") from the closest tree row. Three control points ("I") were marked at a distance varying between 18 and 55 m from the tree rows (except in Lochristi 3). If a sampling plot coincided with a tire track resulting from agricultural machinery use, the sampling plot was repositioned slightly to a location next to the track. The location of transects and sampling plots was maintained as strictly as possible throughout the consecutive sampling years as different crops were rotated on the fields.

In each of the sampling plots, crop yield was measured following a crop-specific protocol. On the fields intercropped with maize, every sampling plot consisted of two neighboring maize rows with a total length of 5 m (interrow distance: 0.75 m). In the case of forage maize, plants were cut manually at approximately 10 cm above ground level, after which the whole plants (including foliage, stem and fruits) were weighed and biomass yield per plot was determined. In the case of grain maize, the cobs were threshed using a Wintersteiger combine (type: *NM-elite*). A similar approach was used for potatoes: two neighboring rows over a total length of 5 m/row were harvested manually. After demarcation of the plots (minimal surface per plot of $1.5 \times 6.5\ m = 9.75\ m^2$), winter wheat and winter barley were harvested using a Wintersteiger combine and the harvested grain (caryopses) was weighed.

2.4. Crop quality

For every plot, a sample of the harvested crop was collected for further quality analyses. Samples were oven-dried at 70 °C to determine the dry matter concentration (%). After grinding, the starch concentration (%) and the organic matter digestibility (OMD) (%) of forage maize and crude protein (CP) concentration (%) of forage maize and winter cereals were determined using Near Infrared Spectroscopy (NIRS). Crude protein yield ($kg\ ha^{-1}$) was calculated based on crop yield data and CP concentrations. For starch, the reference method for the NIRS calibration was ISO 6493, for CP concentration ISO 5983–2, and for OMD, the method described in De Boever et al. (1988). Potatoes were sorted according to diameter to determine the harvest fraction with tuber diameter $>$ 35 mm. Underwater weight (UWW, g per 5 kg tubers) was determined on a sample of the 35–70 mm fraction with an *AW-W8 Explorer underwater weigher*.

2.5. Data analyses

For each crop, yield and quality were analyzed separately for the three size classes using a linear-mixed effect model (LMM). Distances to field edges were transformed logarithmically to linearize the response variables. In case of the young alley cropping fields, the logarithm of the distance to the nearest tree row was used as a fixed effect. For the boundary planted fields, both the logarithm of the distance to the field edge, the presence/absence of a tree row and their interaction were included as fixed effects. The data of all fields have a nested, hierarchical structure with measuring points nested in transects. These transects are in turn nested at the level of the experimental field. To account for year-related effects and the hierarchical nature and non-