BENEFITS OF AGROFORESTRY SYSTEMS FOR LAND EQUIVALENT RATIO – CASE STUDIES IN BRANDENBURG AND LOWER SAXONY, GERMANY

Seserman DM[1*], Veste M[1,2], Freese D[1], Swieter A[3], Langhof M[3]

(1) Institute of Environmental Sciences, BTU Cottbus–Senftenberg, Cottbus, Germany (2) Institute of Botany, University of Hohenheim, Stuttgart-Hohenheim, Germany (3) Institute for Crop and Soil Science, Julius Kühn-Institut, Braunschweig, Germany

*Corresponding author: seserman@b-tu.de

Abstract

Transitioning towards agroforestry demands systematic productivity assessments of such systems under different climatic and edaphic conditions. In this regard, the Land Equivalent Ratio (LER) serves as a valuable productivity indicator of agroforestry since it evaluates yields from growing trees and crops together in comparison to yields from monocultures over the same period. Consequently, our objective was to evaluate the overall productivity of two agroforestry systems in Forst (Brandenburg) and Wendhausen (Lower Saxony) by means of LER. Our approach followed two assumptions: (i) the yields of trees and crops had equal economic importance and (ii) the economic importance was given solely by the annual crop, the yield of trees representing a supplementary profit. The resulted values for LER were consistently above their specific threshold, corroborating the greater efficiency of agroforestry systems rather than monoculture. Additionally, this study highlighted the importance of choosing the appropriate assumptions when calculating the LER.

Keywords: agroforestry; land equivalent ratio; land use efficiency; tree yield; crop yield

Introduction

With comparison to conventional agricultural systems, the integration of trees and arable crops on the same land has been increasingly justified by a range of environmental benefits regarding biodiversity, soil fertility, microclimatic conditions, and overall productivity, and are widely used as wind protection systems against soil erosion (Slazak et al. 2013; Kanzler et al. 2016). However, considering that agroforestry systems have a planning horizon of several decades, the productivity of such systems needs to be periodically assessed for forthcoming risk assessments and adaptation scenarios in the near future.

In this regard, the Land Equivalent Ratio (LER), defined as the relative yield of each tree and crop species in an agroforestry system in comparison to the yield of the same tree and crop species in a monoculture over the same period (Mead and Wiley 1980), was used as a method

[illegible] ndenburg) and Wendhausen (Lower Saxony).

Objectives

Given the fact that land-use systems have different goals, there are different methods of quantifying the LER in agroforestry systems (Ong and Kho 1996). Therefore, the main objective of this study was to evaluate the overall productivity of two agroforestry systems in Forst (Brandenburg) and Wendhausen (Lower Saxony) by means of LER with an emphasis on (i) the yield of both trees and crops (after Mead and Wiley 1980) and (ii) the yield of annual crops (after Ong and Kho 1996) as a principal economical product.

Materials and methods

Study sites

This study was carried out on two agroforestry systems established near Forst (N 51˚47’37’’, E 14˚38’12’’, 67 m a.s.l.) and Wendhausen (N52˚19’54’’, E10˚37’52’’, 85 m a.s.l.). The agroforestry system near Forst is based on a dominantly pseudogleysol type of soil with a loamy sand texture and has an annual average temperature of 9.6°C and an average annual precipitation of 568 mm (DWD Station Cottbus). The agroforestry field near Wendhausen is characterized by a pelosol with a silty clay soil texture and has an average annual temperature of 8.0°C and an average annual precipitation of 616 mm (DWD Station Braunschweig).

The agroforestry system in Forst consists of seven tree strips in a north-south orientation, having a width of 11 m and a total length of 660 m, with agricultural alleys of 96 m, 48 m, and 24 m width between the tree strips (Kanzler and Böhm 2016). The system in Wendhausen consists of four tree strips having a width of 12 m and a total length of 50 m, with agricultural alleys of 48 m width between the tree strips, as well as a control field with short rotation coppices (SRC) planted on a 70 x 70 m surface (Lamerre et al. 2015).

Based on the joint BMBF-Project SIGNAL (Sustainable Intensification of Agriculture through Agroforestry), four core- (agroforestry) and four reference-plots (monoculture) were established on these experimental sites in 2015. Two windward and two leeward core plots were set on the 48 m agricultural alleys and included the first two rows of trees. The planting density was of about 8,700 trees per hectare (1.3 m by 0.9 m within the rows) and 10,000 trees per hectare (2 m by 0.5 m within the rows) for Forst and Wendhausen, respectively (Kanzler and Böhm 2016; Lamerre et al. 2015).

Yield assessment

Regarding the tree yield, first rotation hybrid poplars (*Populus nigra* L. *x P. maximowicii* Henry, clone “Max I”) were harvested at the end of vegetation period 2014 and 2013 in Forst and Wendhausen, respectively. In the second rotation, annual measurements of breast height diameter (BHD) were taken in winter 2015/2016 and 2016/2017. According to these diameter measurements, 25 shoots were chosen, manually cut 10 cm above the ground, chipped and weighted. An allometric equation of the form $M = a\ D^{\ b}$ was used in order to derive the dry matter of all measured diameters, where M is the tree biomass (kg), D is the shoot basal diameter (cm) and a and b are the intercept and slope of a least-square linear regression of ln-transformed data. The yearly tree woody biomass production per hectare was estimated for each core plot using the average number of shoots per hectare and the average dry mass of the shoots, according to the mean stool method (Lamerre et al. 2015).

Regarding the crop yield, winter wheat (*Triticum aestivum* L.) was harvested in 2016 and winter barley (*Hordeum vulgare* L.) was harvested in 2017 in Forst, whereas in Wendhausen winter rapeseed (*Brassica napus* L.) was harvested in 2016 and winter wheat in 2017. Due to the fact that different crops were grown at the agroforestry systems in Forst and Wendhausen, we used a normalized crop unit (GE; “Getreideeinheit”) in order to calculate and compare the agricultural production per hectare. Accordingly, 1 dt wheat corresponded to 1.04 GE, 1 dt barley to 1.00 GE, and 1 dt rapeseed to 1.30 GE (Schulze Mönking and Klapp 2010).

Regarding the monoculture systems, we distinguished between the reference crop plot as the agricultural system and the reference tree plot as the SRC. Lacking an identical planting scheme of trees between the agroforestry systems and SRC, we assumed that the annual biomass increments of the inner rows of the agroforestry system are comparable to those in the SRC. Thus, in Forst, measurements were collected from four double-row plots with poplar trees and we assumed the inner two rows as similar to an SRC. In Wendhausen, measurements were collected from the SRC planted on the control field.

Land equivalent ratio

The land equivalent ratio (LER) is the ratio between the relative yield of each tree and crop species in an agroforestry system in comparison to the yield of the same tree and crop species in a monoculture over the same period.

Firstly, we calculated the LER for each system under the assumption that the yields of trees and crops are of equal economic importance, after Mead and Wiley (1980):

$$LER1 = \frac{Yield\ Tree\ Agroforestry}{Yield\ Tree\ Reference} + \frac{Yield\ Crop\ Agroforestry}{Yield\ Crop\ Reference} \quad \text{(Eq. 1)}$$

While LER1 ≤ 1 means that there is no productivity advantage of agroforestry over monoculture, a LER1 > 1 suggests that the production in the agroforestry system is higher than the one in a monoculture system.

Secondly, we calculated the LER for each system under the assumption that the economic importance is given solely by the annual crop, as the yield of trees is generally regarded as a supplementary profit. Consequently, the difference in crop yield resulting from the presence of trees relative to the yield of the sole crop was determined according to Ong and Kho (1996):

$$LER2 = \frac{Yield\ Agroforestry\ System - Yield\ Crop\ Reference}{Yield\ Crop\ Reference} \quad \text{(Eq. 2)}$$

In this case, LER2 > 0 suggests that the production in the agroforestry system is higher than the one in a monoculture system.

Results and discussion

The land equivalent ratios show considerable differences between the two agroforestry sites over the investigated two years (Figure 1).

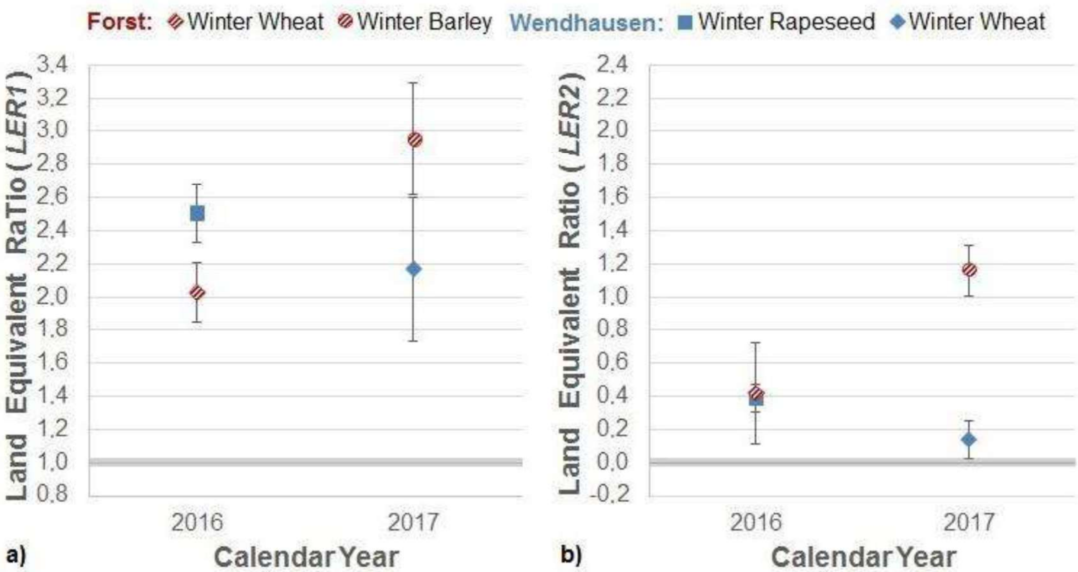

Figure 1: The land equivalent ratio with regard to the variation of data calculated for the agroforestry systems in Forst and Wendhausen after Mead and Wiley 1980 – LER1 (a) and after Ong and Kho 1996 – LER2 (b). The grey line serves as a threshold above which the agroforestry system has greater productivity than the monoculture system.

All of the obtained values for LER were consistently higher than their specific threshold, meaning that in both cases and for both locations, the agroforestry system had a greater productivity than the monoculture system. Regarding the LER calculations according to Mead and Wiley (1980), the agroforestry systems in Forst and Wendhausen achieved values between 2.0 and 2.9, respectively. Relatively lower results were reported by van der Werf et al. (2007) and Graves et al. (2007), with an LER value between 1.0 and 1.8, as calculated after Mead and Wiley (1980).

Mentionable would also be the fact that changing the purpose of land-use, i.e. the method of calculating the LER can lead to contradictory conclusions. For example, in 2016, Wendhausen was the more productive field according to LER1, whereas both sites showed similar productivity according to LER2.

Conclusion

Our results corroborate the greater efficiency of land use, i.e. greater land equivalent ratios when trees were integrated with arable crops rather than grown as sole crops and highlight the importance of choosing the appropriate method when calculating the land equivalent ratio.

Acknowledgements

We are grateful to our colleagues at the Chair of Soil Protection and Recultivation, BTU Cottbus – Senftenberg, and the Julius Kühn-Institut in Braunschweig, for their support and scientific collaboration. Additionally, we thank the Agrargenossenschaft Forst/L. e.G. for their promotion and management of the agroforestry systems at Forst. The research was carried out under the BonaRes - SIGNAL project (FKZ 031A562E, 2015-2018) and funded by BMBF - German Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung).

References

Graves AR, Burgess PJ, Palma JHN, Herzog F, Moreno G, Bertomeu M, Dupraz C, Liagre F, Keesman K, van der Werf W, Koeffeman de Nooy A, van den Briel JP (2007) Development and application of bio-economic modelling to compare silvoarable, arable, and forestry systems in three European countries. Ecol Eng 29: 434–449.

Kanzler M and Böhm C (2016) Nachhaltige Erzeugung von Energieholz in Agroforstsystemen (AgroForstEnergie II): Teilvorhaben 2: Bodenschutz, Bodenfruchtbarkeit, Wasserhaushalt und Mikroklima. Schlußbericht, Brandenburgische Technische Universität Cottbus-Senftenberg, Fachgebiet für Bodenschutz und Rekultivierung, Cottbus.

Kanzler M, Böhm C, Mirck J, Schmitt D, Veste M (2016) Agroforstliche Landnutzung als Anpassungsstrategie an den Klimawandel. Mitteilungen der Gesellschaft für Pflanzenbau 28: 126–127.

Lamerre J, Langhof M, Sevke-Masur K, Schwarz KU, von Wühlisch G, Swieter A, Greef JM, Dauber J, Hirschberg F, Joormann I, Krestel N, Masur D, Reith C (2016) Nachhaltige Erzeugung von Energieholz in Agroforstsystemen: Teilprojekt 3: Standort Niedersachsen; Strukturvielfalt und Biodiversität. Schlußbericht, Julius Kühn-Institut Bundesforschungsinstitut für Kulturpflanzen (JKI) - Institut für Pflanzenbau und Bodenkunde, Braunschweig.

Mead R and Willey RW (1980) The concept of a "Land Equivalent Ratio" and advantages in yields from intercropping. Exp Agr 16: 217–228.

Ong CK and Kho RM (1996) A framework for quantifying the various effects of tree-crop interactions. In: Ong CK and Huxley P (eds) Tree–crop interactions: a physiological approach. CAB International, Wallingford, pp 1–23.

Schulze Mönking S and Klapp C (2010) Überarbeitung des Getreide- und Vieheinheitenschlüssels. Endbericht, Georg-August-Universität Göttingen - Forschungs- und Studienzentrum für Landwirtschaft und Umwelt, Göttingen.

Ślązak A, Böhm C, Veste M (2013) Kohlenstoffspeicherung, Nährstoff - und Wasserverfügbarkeit. In: Wagener F, Heck P, Böhmer J (eds) Nachwachsende Rohstoffe als Option für den Naturschutz. Naturschutz durch Landbau? Schlussbericht, ELKE III, Hochschule Trier, Umwelt-Campus Birkenfeld, pp 130–149.

Van der Werf W, Keesman K, Burgess PJ, Graves AR, Pilbeam D, Incoll LD, Metselaar K, Mayus M, Stappers R, van Keulen H, Palma J, Dupraz C (2007) Yield-SAFE: A parameter-sparse, process-based dynamic model for predicting resource capture, growth, and production in agroforestry systems. Ecol Eng 29: 419–433.