Europ. J. Agronomy 83 (2017) 15–27

Contents lists available at ScienceDirect

European Journal of Agronomy

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

A new method for analyzing agricultural land-use efficiency, and its application in organic and conventional farming systems in southern Germany

Hung-Chun Lin*, Kurt-Jürgen Hülsbergen

Lehrstuhl für Ökologischen Landbau und Pflanzenbausysteme, Technische Universität München, Germany

ARTICLE INFO

Article history:
Received 8 April 2016
Received in revised form 2 November 2016
Accepted 4 November 2016

Keywords:
Land-use efficiency
Organic farming
Conventional farming
Agroforestry
Mixed farming
Arable farming

ABSTRACT

Improving the land-use efficiency (LUE) of farming systems could satisfy increasing global food, feed, biomass and bioenergy demand in a sustainable manner. This study presents a new method for calculating LUE, beginning with an overview of different approaches to assessing agricultural LUE. This new method takes into account the quality and function of agricultural products and the relationship between the yield of the assessed farm and the average yield of the reference region with comparable soils, climate and socio-economic conditions.

The new approach was tested using data from long-term experiments at the Scheyern Research Farm in southern Germany, which include different farming systems (organic mixed farming, arable farming, and agroforestry; conventional arable farming and agroforestry). In our case studies, the LUE of conventional systems (arable farming: 1.00; improved arable farming: 1.06; agroforestry: 0.98) was higher than those of the organic systems (mixed farming: 0.69; arable farming: 0.33; agroforestry: 0.43) due to different crop rotations, dry matter yields, and biomass usage (harvest ratio). The conversion of high-input arable farming systems (conventional farming) to agroforestry systems is an extensification with negative effects on the dry matter yield and land-use efficiency. Nevertheless, the conversion to agroforestry systems can increase dry matter yield and land-use efficiency in low-input arable farming systems (organic farming). LUE should be used in combination with agri-environmental indicators, in order to ensure both efficient and sustainable land use.

1. Introduction

Global agriculture is facing an urgent challenge in delivering food security (Davies et al., 2009; Popp et al., 2014). Recent studies show that agricultural production needs to be roughly doubled by 2050 to fulfill the high demand resulting from increasing population, dietary change, and bioenergy use (Foley et al., 2011; Tomlinson, 2013). The expected high demand for agricultural products will further intensify global pressure on land. Land is one of the most limited resources in agriculture. However, land degradation such as erosion, salinization, and desertification induced by human activities has reduced the amount of agricultural land suitable for agricultural production (Gao and Liu, 2010; García-Orenes et al., 2012). Land degradation damages soil quality, which has a negative influence on crop yield, and hence may also reduce energy- and nitrogen-use efficiency. Therefore, to meet increasing demand without further destruction of non-agricultural land, the use of existing agricultural land has to be more efficient, while at the same time ensuring the quality of this land.

Efficiency is usually defined as output in relation to input, but there is neither a general definition of agricultural land-use efficiency (LUE), nor a standard measurement method for LUE. LUE is often used synonymously with agricultural crop yield (dry matter yield per unit of agricultural land area) (Carpenter et al., 2002; Reinhardt et al., 2007; Boehmel et al., 2008; Prabhakar and Elder, 2009). Other common indicators for LUE are energy yield (energy output (Hülsbergen et al., 2001)), net energy yield (heating value of harvested biomass minus energy input for production (Lewandowski and Schmidt, 2006; Boehmel et al., 2008)), yield ratio (ratio of harvested dry biomass of two systems (Mondelaers et al., 2009; Seufert et al., 2012)), grain equivalent (GE, an aggregation unit taking into account the different chemical composition and nutritional value of crops (Hülsbergen et al., 2001)), land equivalent ratio (LER, relative land area in monocropping that is required

* Corresponding author.
E-mail address: hc.lin@mytum.de (H.-C. Lin).

http://dx.doi.org/10.1016/j.eja.2016.11.003
1161-0301/

Table 1
Indicators for land-use efficiency. The symbol + means that the indicator takes the influencing factor into account, the symbol − means that the indicator does not take the influencing factor into account.

Indicator	Unit	Definition	Example of use	Advantages	Restrictions	Influencing factors			References
						Quality of products	Regional yield potential	Function of the assessed products	
Crop yield	Mg ha^{-1} yr^{-1}	Fresh matter or dry matter yield per unit of agricultural land area	Analyzing the effects of inputs and management	Less analysis effort, accepted indicator	Different crops/products cannot be compared	–	–	Food, feed, biomass, bioenergy	Carpenter et al. (2002); Boehmel et al. (2008); Prabhakar and Elder (2009)
Yield ratio	dimension-less	Ratio of harvested biomass of two systems	Comparing farming systems (organic vs. conventional)	Less analysis effort, easy to understand	Different crops/products cannot be compared	–	–	Food, feed, biomass, bioenergy	Mondelaers et al. (2009); Seufert et al. (2012)
Grain equivalent (GE)	GE ha^{-1} yr^{-1}	Aggregation unit, considering the chemical composition and nutritional value of biomass	Comparing crop rotations and farming systems	Quality of products is expressed in one parameter	Not defined for biomass and bioenergy production	+	–	Food and feed	Hülsbergen et al. (2001); Schulze Mönking and Klapp (2010)
Energy yield (Energy output)	GJ ha^{-1} yr^{-1}	Heating value of harvested biomass	Energy balance, analyzing farming systems	Energy content of products is considered	Different energy quality is not considered	+	–	Food, feed, biomass, bioenergy	Hülsbergen et al. (2001)
Net energy yield	GJ ha^{-1} yr^{-1}	Energy yield minus energy input for production	Determining the optimum nitrogen intensity	Energy content of products is considered	Different energy quality is not considered	+	–	Food, feed, biomass, bioenergy	Lewandowski and Schmidt (2006); Boehmel et al. (2008)
Food energy yield	kcal ha^{-1} yr^{-1}	Human-edible calories after conversion and processing	Comparing food systems (e.g. plant and animal production)	Product use and conversion losses are considered	Biomass and bioenergy production is excluded	+	–	Food and feed	Suggested by Seufert et al. (2012)
People nourished per hectare	People per ha	People actually fed per hectare of cropland (agricultural land)	Analyzing the contribution of a food system to the human diet	Livestock conversion efficiency is considered	Food waste is not considered	+	–	Food energy	Cassidy et al. (2013)
Land equivalent ratio (LER)	dimension-less	Land area required from monocropping to produce the yields from intercropping	Comparing monocropping and intercropping systems	Could be applied to all products	Quality of products is not considered	–	+	Food, feed, biomass, bioenergy	Agegnehu et al. (2006); Smith et al. (2013)
Area time equivalent ratio (ATER)	dimension-less	LER taking into account the growing period of crops	Comparing monocropping and intercropping systems	Could be applied to all products	Quality of products is not considered	–	+	Food, feed, biomass, bioenergy	Polthanee and Trelo-ges (2003); Verma et al. (2013)
Land-use efficiency (LUE)	dimension-less	Ratio of farm yields to average yields of the region	Comparing crop rotations and farming systems	Could be applied to all products	Availability of regional statistical data	+	+	Food, feed, biomass, bioenergy	This study

to produce the yields in intercropping (Agegnehu et al., 2006)), and area-time equivalent ratio (ATER, LER with consideration of the growing period of crops from planting to harvesting (Polthanee and Trelo-ges, 2003)). Cassidy et al. (2013) suggested redefining agricultural crop yield from crop tons per hectare to people nourished per hectare; this new unit could also be regarded as an indicator for LUE. A short review of these indicators is shown in Table 1.

However, many of the LUE indicators in Table 1 have not adequately considered the quality of agricultural products, or have excluded the influence of regional yield potential in the results. Quality (e.g. protein and energy content) is the most important property of agricultural products, especially for markets and consumers. The yield potential of one region (both the administrative and the soil and/or climate region) is influenced by natural site conditions, as well as socio-economic factors (e.g. production intensity, choice of crops/cultivars, available technologies). A farm with good soil quality or high production intensity (high-input system) may have higher yields compared to a farm with poor soil quality or lower production intensity (low-input system). It is not appropriate to compare farming systems when the difference in product quality and quantity is influenced by different natural site conditions and yield potentials.

In addition, simply comparing individual crop yields does not suffice for an adequate evaluation of LUE (Seufert et al., 2012); an analysis of the LUE of crop rotations and whole farming systems is necessary. In addition to crop yield and quality, the biomass