Soil & Tillage Research 157 (2016) 73–82

Contents lists available at ScienceDirect

Soil & Tillage Research

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

Energy use and input–output costs for sunflower production in sole and intercropping with soybean under different tillage systems

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ARTICLE INFO

Article history:
Received 12 July 2015
Received in revised form 4 November 2015
Accepted 21 November 2015
Available online 2 December 2015

Keywords:
Energy profitability
Glycine max L.
Helianthus annuus L.
Intercropping
Land use efficiency
Yield performance

ABSTRACT

Agriculture is an important energy user and energy supplier in the form of bio-energy. In today's agricultural practices, soil tillage and applications of chemicals are the greatest consumers of energy and labor. Therefore, selection of an appropriate tillage method and finding an efficient way for decreased consumption of chemicals can improve energy use and reduce costs. The pre-requisite for such improvements includes assessment of the system's energy balance. Moreover, intercropping can play an important role in improving yield and reducing energy consumption. To compare the effects of different tillage treatments on energy use and grain yield in a sunflower-soybean intercropping system, a field experiment was performed on a clay loam soil at the Agricultural Research Station, Faculty of Agriculture, University of Bu-Ali Sina, Hamedan, Iran, during the growing seasons of 2013 and 2014. Three levels of tillage, as the main factor, and different planting patterns were tested in sub-plots (sole crop of sunflower, sole crop of soybean, and additive intercroppings of sunflower + 30%, 60% and 90% soybean). The intercropping design was additive. Results showed that sunflower grain yield was significantly affected by the planting pattern. Tillage treatments did not have significant effects on the sunflower yield. The highest sunflower grain yield (356.22 g m^{-2}) was obtained from the sole crop of sunflower. Furthermore, amongst intercropping treatments, the highest sunflower grain yield (302.44 g m^{-2}) was achieved from the combination of sunflower + 60% soybean. Also, comparison of the combined treatments indicated that the highest energy output (248363 MJ ha^{-1}) and energy use efficiency (7.44) were reached with the combinations of conventional tillage × sunflower + 90% soybean, and minimum tillage by disc × sunflower + 90% soybean, respectively. In conclusion, using minimum tillage and intercropping system of sunflower + 60% soybean can decrease energy consumption and increase total yield and land use efficiency when compared to sunflower sole crop under conventional tillage.

1. Introduction

Agricultural systems are known as both producers and consumers of energy. They use large quantities of locally available non-commercial and commercial energies in direct and indirect forms, such as mineral fertilizers, biocides, machinery, diesel fuel, electricity (mostly for irrigation), manure, animals and seeds. Indeed, energy is mostly needed for tilling, crop protection, irrigation, weed management, harvesting, and other processing practices in agriculture (Moreno et al., 2011). Intensive use of energy in agricultural systems can be attributed to multiple factors including application of chemical fertilizers, cultivation of high yielding seeds, consumption of synthetic pesticides and mechanization of production. Thus, resolving energy balances is an important aspect of modern agriculture as a producer and user of energy (Ozkan et al., 2004). Efficient use of energy contributes to the economy through increased profitability, productivity and competitiveness of agricultural sustainability in rural areas (Ozkan et al., 2004; Singh, 2002). The ever-increasing demand for food forces farmers to use energy resources for agricultural production more intensively. However, more intensive energy use has brought about some important health and environmental issues, calling for more efficient use of inputs to maintain a sustainable agricultural production (Yilmaz et al., 2005; Esengun et al., 2007). Increasing the energy efficiency not only improves competitiveness through cost reduction but also results in minimized energy-related environmental pollution, thus positively contributing towards sustainable development (Ozkan et al., 2004). To study the efficiency and environmental impacts of production systems, energy input-output balance should be evaluated. This analysis will determine how efficient the energy is used.

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http://dx.doi.org/10.1016/j.still.2015.11.008

Energy use efficiency can be increased by improving outputs such as crop yield and by reducing inputs such as tillage operations and consumption of herbicides, pesticides and fertilizers. In some cases, a reduction in energy inputs entails a proportional reduction in crop yield, but in such cases, energy efficiency is not significantly affected (Bailey et al., 2003). An important strategy to reduce energy consumption is agricultural conservation. Agricultural conservation technologies maintain water and soil, keep soil moisture and increase crop yield and soil quality, which are beneficial to the sustainable development of agricultural production (Balwinder-Singh et al., 2011). Compared with conventional tillage, subsoiling has been found to decrease the effect of soil compaction on crop growth (Jennings et al., 2012) but increase rooting depth and the amount of water available to the crop as well (Mohanty et al., 2007). Hence, conservation tillages may improve crop yield, among other economic benefits (Fabrizzi et al., 2005). Guzha (2004), however, observed that wheat yields from no tillage and minimum tillage treatments were lower than those from traditional tillage treatments. Thus, before conservation tillage practices become widely adopted in any particular region, their suitability should be locally assessed.

In addition to conservation tillage, intercropping is also considered as another way to reduce energy consumption. Intercropping, which is defined as growing two or more species simultaneously in the same field during a growing season (Yan et al., 2014), has been considered as an important strategy for developing sustainable production systems, particularly systems that aim to limit external inputs such as chemical fertilizer and herbicide (Dhima et al., 2007). Intercropping is a sustainable cropping practice that has been successfully implemented in agro ecosystems of Southeast Asia, India, China, Africa and Latin America, (Yan et al., 2014). Intercropping is still widely used for increasing crop yield in tropical regions so that it not only enables optimal distributions of space and resources (Dhima et al., 2007) but also offers several major advantages, such as effective utilization of fertilizers (Javanmard et al., 2009) and greater resistance to pests, diseases and weeds (Vasilakoglou et al., 2008). These advantages presumably result from both above- and below-ground facilitation between intercropped species (Li et al., 2006). Spatial effects are determined by the distribution of roots, which vary in different intercropping systems due to specific characteristics of intercropped species in rooting depth and/or seasonality (Li et al., 2007, 2010; Zhang et al., 2004).

Typical species or functional groups used in intercropping include cereals (i.e. wheat, barley, rye, and oats), legumes (i.e. clover, beans, peas, and vetch), and non-leguminous forbs (i.e. buckwheat, flax, and chicory). Also, sunflower is an important crop for intercropping because this crop has an important role in controlling weeds and pests (Fuente et al., 2014; Chen et al., 2012). Some guaianolide skeletons and heliannuol and sesquiterpene lactones have been isolated from different cultivars of sunflower and their potential roles as natural herbicides have been investigated (Macías et al., 2002). Moreover, it has been reported that sunflower attracts and hosts numerous beneficial insects (Jones and Gillett, 2005). When one crop species is nitrogen fixing, the range of ecological services provided by the intercrop expands to include nutrient management. Overall, the range of benefits conferred by intercropping two or more species include higher productivity and profitability per unit area (Yildirim and Guvence, 2005), improved soil fertility through nitrogen fixation (Hauggaard-Nielsen et al., 2009), increased efficiency of resources (Knudsen et al., 2004), reduced damage caused by pests, diseases and weeds (Banik et al., 2006), improved forage quality (Bingol et al., 2007; Lithourgidis et al., 2007) and improvements in carbon and nitrogen dynamics (Oelbermann and Echarte, 2011; Dyer et al., 2012).

Taken all together, although several advantages for the use of intercropping and its positive role in improving energy efficiency are reported, the effects of tillage and intercropping systems on energy efficiency of sunflower production in relation to soybean has not been yet investigated. Thus, the main objective of this work was to compare the energy use in three tillage and intercropping systems by assessing the grain yield and quality properties of sunflower and soybean seeds and determining the land equivalent ratio (LER) in intercropping system compared to sole cropping treatment.

2. Materials and methods

2.1. Study area and experimental design

A split plot experiment was designed based on randomized complete blocks with three replications, which was implemented on a clay loam soil (pH 7.49, 0.428 dS/m EC and 1.18% organic matter) during the growing seasons of 2013 and 2014, at the Agricultural Research Station, Faculty of Agriculture, University of Bu-Ali Sina, Hamedan (latitude 35°1′ N, longitude 48°31′ E and 1690 m altitude), Iran. Microclimatological data for experimental location is summarize in Table 1.

Sub-plots were defined based on minimum (by chisel or disc) and conventional (by moldboard) levels of tillage as the main factor, as well as different planting patterns (sole crop of sunflower, sole crop of soybean, additive intercropping of sunflower + 30% soybean, sunflower + 60% soybean, sunflower + 90% soybean).

2.2. Supplementary data

Before beginning our work, the experimental land was under fallow. Twenty days before planting, the soil was tilled by harrow for conventional tillage and by chisel and disc for minimum tillage. Sunflower and soybean were considered as main and secondary crops, respectively. The crops' seeds were simultaneously sown on May 31, 2013 and June 1, 2014. Plots had 4 m length and 3 m width. Soybean was planted in 6 rows with 50 cm row spacing, and the density of 40 plants per m^{-2} for sole cropping. Sunflower was planted in 5 rows with 60 cm row spacing and the density of 9 plants m^{-2}. 75 and 250 kg urea fertilizer ha^{-1} was applied for soybean sole crop and other treatments, respectively. After sowing, every week plants were irrigated by a sprinkler system. The total amount of irrigation water applied to each plot was about 620 mm.

Plants were harvested on September 30, 2013 and September 27, 2014. After considering border effect (0.5 m top and bottom of

Table 1
Microclimatological data for experimental location.

Month	Max temperature (°C)		Ave temperature (°C)		Min temperature (°C)		Rainfall (mm)	
	2013	2014	2013	2014	2013	2014	2013	2014
June	31	31	21	22	12	13	0	0
July	36	35	26	25	16	15	0	0
August	34	35	24	25	14	15	1.9	1.5
September	30	30	19	20	9	10	0.6	1.0