Journal:

Field Crops Research

Analytic review on Land Equivalent Ratio

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Abstract

Trends in agricultural production systems have evolved to achieve high productivity and promote sustainability over time in recent years. One of the most used practices which improve productivity is intercropping. Intercropping, the cultivation of two or more crop species simultaneously in the same field, has been widely practiced by smallholder farmers gaining increasing interest. Which makes better utilization of land, sole or multiple cropping? How many acres of sole-cropped A and sole-cropped B, for example, would be needed to equal the productivity of intercropped A and B? Several measures are used to compare the productivity of sole and multiple cropping systems but, we will focus on the most used which is Land equivalent ratio (LER). A review of 36 publications that have examined the land equivalent ratio in 17 countries is provided. The land equivalent ratio can be defined as the ratio of land area needed under sole cropping to the area of intercropping at the same management level to obtain an equal amount of yield. This study evaluates, explores, and synthesizes what factors affect LER in the ERA dataset and study the contribution of individual species to LER using meta-analysis.

Introduction

Natural disasters, over-population, low food production, and food distribution are causes of food insecurity in Africa and other developing countries. Most of the farmers in Africa are small-scale farmers. It has been recorded that about 800 million people in developing countries do not have sufficient food according to an FAO report on food Insecurity in the world in 2000. Most of these populations live in rural regions with a limited numbers experiencing food security and small-scale farming plays an important role (Van Rooyen and Sigwele, 1998). The high variation in the potential of natural resource-based farming is characterized by the variable rainfall in arid and humid zone. The common aim of farmers and agriculturists is improvement of crop productivity, mostly using the poly-culture cropping system traditionally used in developing countries. Multiple cropping systems or intercroping involve integrating crops using space and labor more efficiently, that is the main reason why it is used (Baldy and Stigter, 1997).

During recent years It has become widely recognized that intercropping can often produce higher yields than solo crops. According to (Willey, 1990; Hauggaard-Nielsen et al., 2008), Intercropping is defined as the cultivation of two or more crop species in the same field for the whole or part of their growing period. Why is this term so common? In one of the most complete reviews of the subject, Lamberts (1980) cites the following reasons for intercropping: increased productivity/yield advantages; better use of available resources such as land, labor, time, water, nutriments; reduction in damage caused by pests: diseases, insects, weeds; socio-economics and other advantages: greater stability, economics, human nutrition, biological aspect. In the present work, we will not treat all these factors but only those related to the Land equivalent ratio. There are four subcategories of intercropping: mixed intercropping, row intercropping, strip intercropping, and relay intercropping. Intercropping is an ancient agronomic practice and was applied worldwide. It however has gradually disappeared in developed countries due to mechanization and the availability of cheap synthetic fertilizers and pesticides which make sole cropping an efficient way to go (Horwith, 1985; Machado, 2009).

One of the challenges facing the world is to match the rapidly changing demand for food from an increasing population with limited land, using environmentally friendly agricultural methods (Godfray et al., 2010). Given the advantages of intercrops, intercropping has the potential to contribute to the sustainable intensification of modern agriculture (Bedoussac et al., 2015; Jensen et al., 2015). Therefore, intercropping is currently receiving renewed interest as an environmentally friendly agronomic practice in developed countries. In this study, we want to determine whether a given intercropping combination is indeed better than sole cropping and whether, within that combination, intercropping practice is better than another based on their LER values.

Land-use efficiency is one of the most widely studied aspects of intercropping research. The land equivalent ratio compares the Land-use efficiency of an intercrop to that of sole crops. Many research papers show large variation in Land equivalent ratio. Most studies (about 80%) mentioned values of LER above one, but some mentioned values below one. (Fadl et al., 2012) have been able to obtain a very high value of LER up to 3.8 with (Acasia senegal/Sesame) but like I mentioned earlier, most of them are slightly greater than unity:1.1-1.3 (Maize-common bean, Alemayehu et al., 2017), 1.41 (maize/faba bean, Mei et al., 2012), 1.83 (sorghum/groundnut, Harris et al., 1987). While few Studies have attempted to generalize and quantitatively synthesize what factors contribute to variation in LER, and which species under what conditions contribute to a high LER, the objective of the present work is to synthesize different factors leveraging the variation of LER.

Research methodology

Although work had been done since 1979, when (R. MEAD and R. W. Willey, 1980) first reported the concept of a land equivalent ratio and advantages in yields from intercropping. We are interested in criteria for evaluating different intercropping situations using the Land Equivalent Ratio (LER) concept. The large variability in LER is unexplained and no quantitative analysis of the causes of this variability across systems has been made. We will use meta-analysis as the main research methodology which is a set of statistical methods to quantitatively review and synthesize published information on a topic. We will describe the distribution of the effect sizes associated with a set of experiments. Evidence for Resilient Agriculture (ERA) is a platform that delivers data and tools designed to pinpoint what agricultural technologies work where. Built on the last 30-plus years of agriculture research, ERA provides a comprehensive synthesis of the effects of shifting from one technology to another on key indicators of productivity, system resilience, and climate change mitigation. Data has been compiled on more than 250 agricultural products. Management practices, outcomes, and products are nested within respective hierarchies, allowing ERA to aggregate and disaggregate information. In this study, we are interested in Land equivalent ratio outcomes.

Influence of agronomic practices

It has been shown that plant-plant interactions depend on environmental context, with competitive interactions dominating in favorable environments (Brooker et al., 2008; He et al., 2013). The hypothesis in the context of intercropping shows the importance of interactions at high N input, but possibly greater importance at low N input (Patra et al., 1986; Jensen, 1996). This demonstrates that the application of nitrogen fertilizer may influence the interspecific interactions in intercrops and as such LER. (Vandermeer, 1992) shows that another factor determining intra and interspecific interactions is the sowing density of component species. Therefore, the productivity might increase when increasing the density of one species in an intercrop while decreasing the productivity of the associated species (Braakhekke, 1980; Gardiner and Craker, 1981; Fawusi et al., 1982). Species interactions might also be affected by different ways of mixing them. There are roughly 17 Practices in the framework of our study.

Statistical approach

Meta-analysis (Koricheva et al., 2013) is used to synthesize information from the ERA dataset (see appendix), and determine the key system and plant traits affecting LER. Based on the collected data from publications, the expected responses of independent variables (crop type combination and agronomic practices) to dependent variables LER or PLER are studied. Other factors such as weather conditions, soil fertility, or other aspects of soil quality will be studied even though they cannot be quantified, using a meta-analysis which is a statistical way to combine research results across studies.

Study Area:

For each study, the experiments were carried out over different seasons and different areas. The outcome ratios in the ERA dataset have been analyzed for each combination of Land equivalent ratio outcome and practices. The following map is showing the density of ERA observations for the Land equivalent ratio outcomes across Africa in 17 countries in total. We observe a bias in the spatial distribution of studies with a lot of studies in west Africa more precisely, in Ruaca, Namibia. The reporting period is from 1991 to 2018 in 46 locations

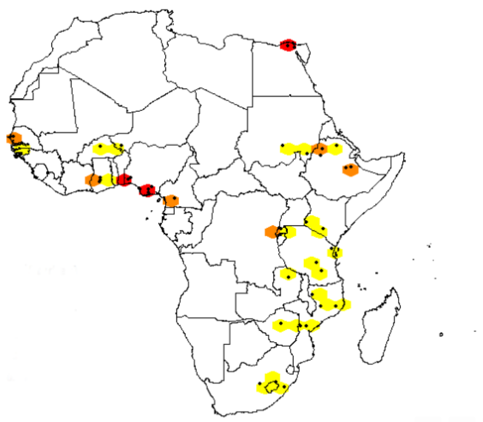

Fig 1 *Locations reporting LER across Africa*

The Land equivalent ratio concept

Land equivalent ratio and Relative Yield are the most important techniques to accurately assess the effectiveness of intercropping in terms of land resource utilization and productivity by associated crops (Y Yu, 2016). The land equivalent ratio (LER) is defined as the relative land area required as sole crops to produce the same yields as intercropping. It was estimated through the following relationship (Willey and Osiru, 1972)

$$LER = L_A + L_B = \frac{Y_A}{S_A} + \frac{Y_B}{S_B}$$

Where L_A and L_B are the LERs for individual crops, Y_A and Y_B are the individual crop yields in intercropping, S_A and S_B are their yields in solo crops. LERs can be compared between different crop combinations and crops can be added to form combined yields. LER ≥ 1, yield advantage for intercropping (intercropping is better than monocropping). LER = 1, intercropping has no advantage over monocropping; LER ≤ 1, yield disadvantage for intercropping (the system suffers from competition).

Data analysis

Data analysis was conducted using R version 4.1.0 for each study. The minimum data requirements are met. Linear-mixed effects or linear model is applied to the data to generate means, standard errors, and variance. Individual observations are up-weighted by replication and down-weighted by the number of observations submitted from the same study for each combination of grouping variables. To evaluate practice performance, we used the Shapiro-Wilk normality test (Shapiro, S.; Wilk, M., 1965) for each combination of grouping variables.

Results and Discussion

Land Evaluation:

The soil types for all studies are stations and farms with values of pH between 4.3 and 8.9. The status of soils in terms of selected properties is shown in Table 2. Soils were sandy, clayey and mostly acidic and of medium organic matter content. A total of 63 species combinations have been studied in 46 sites (see the table in appendix).

LER

Some studies indicated a high value of LER and the highest was observed with spice crops agroforestry system (T Reyes et al., 2009) during the study of two popular cash crops, cardamom (Elettaria cardamomum (L.) Maton.) and black pepper (Piper nigrum L.) in Tanzania. Other studies reporting the range values of LER with different combinations of practices are recorded in **table 2**

Combinations	LER	Date	Countries	References
Intercropping of sesbania and leucaena with five annual grasses	1.23 - 4.65	2001	Egypt	M Abbas et al.
Maize–common bean intercropping	1.1-1.3	2017	Ethiopia	M Latali et al.
Sorghum–cowpea intercropping	1.44 - 1.54	2016	South Africa	TO Oseni et al
Crop Rotation-Intercropping of cassava, maize, soya bean, and cowpea	1.27 - 2.83	2003	Ghana	HK Dapaah et al.
Influence of Acacia senegal agroforestry system on growth and yield of sorghum, sesame, roselle and gum	3.3 - 3.8	2012	Sudan	Kem Fadl et al.
Cotton – Wheat Relay Intercropping	1.65- 2.65	2015	Egypt	Galil et al.
diverse cropping systems under a new agricultural policy environment	1.01 - 1.65	2016	Rwanda	KB Isaac et al.
Productivity of hedgerow shrubs and maize under alleycropping and block planting systems	1.09 - 1.28	1995	Kenya	BA Jama et al.
Intercropping Maize with Peanut under Sandy Soil	1.64 - 1.69	2018	Egypt	Metwally et al.
Intercropping maize with lablab	1.39 - 1.59	2018	South Africa	BE thembu et al.
intercropping of cassava and maize	1.10 - 1.70	1994	Nigeria	FO lasantan et al.
Influence of different acasia senegal	0.55 - 2.29	2006	Sudan	Kamal Eldin Mohammed
Pearl millet and cowpea yields in sole and intercrop systems	1.43 - 1.48	1990	Niger	KC Reddy et al.
Spice crops agroforestry systems	2.22 - 4.47	2009	Tanzania	T Reyes et al.
Productivity and seed cost reduction	1.1 - 2.1	2017	Tanzania	Rusinamhodzi et al.
Maize–grain legume intercropping	1.1 - 2.4	2012	Mozambique	Rusinamhodzi et al.
Cotton–cowpea intercropping	1.3 - 1.4	2006	Zimbabwe	Rusinamhodzi et al.
cassava-vegetable intercrops	1.78 - 2.06	2015	Nigeria	AW Salau et al.
Combining soil fertilization, cropping systems and improved varieties	1.11 - 1.88	2016	Burkina Faso	J Sanou et al.
Intercropping (Living Cover)and Mulching(Desiccated Cover)	1.34–1.95	2016	Senegal	OQ Abaye et al.
Reduced Tillage and Intercropping as a Means to Increase Yield and Financial Return	1.87-2.12	2018	Ethiopian	A Tsegay et al.

***Table 1**: The combination of species and the associated interval value of LER, years and countries.*

Measurements and evaluation

About 407 intercropping in 29 different studies have been examined with different values of LER in the range 0.11-4.8. For instance, (Galil, 2015) achieved the highest LER of 2.65 using relay intercropping culture by growing wheat plants and cotton. Table 4 shows a more general picture of the analysis at the practice level. Outcome Land equivalent ratios in the ERA dataset for each combination of grouping variables are analyzed by practice names. The Land equivalent ratio outcome has been analyzed. These are ratios between an experimental treatment and control outcome and are approximately normally distributed. We observe that studies with more replications are likely to produce less variable information than studies with fewer. Controlling for the number of observations contributed by a study to the dataset weights each study equally. As such, outcome ratios are weighted according to:

Weighting = ((Reps* RepsC)/(RepsE)+(RepsC))/(Ns)

where Rep is the number of replications for RepC the control and RepE the experimental treatment, and Ns is the total number of observations contributed to the overall dataset by the study to which the observation belongs. The Shapiro-Wilk normality test has been applied for each combination of grouping variables to judge whether values based on mean proportional change, mean response ratio or median proportional change should be used to evaluate practice performance. The response ratios (the ratio of mean outcome in the experimental group to that in the control group) are back-transformed and converted to percentage change with and without a correction for the Jensen inequality. The correction applied is as per (Tandini & Mehrabi 2017).

Land equivalent ratio is sometimes used to evaluate productivity. In general, it increases with productivity across systems (V. Chimonyo et al., 2015). One of the key factors for high productivity is plant traits diversity and temporal and spatial arrangements of plant mixtures. We studied spatial and temporal crop diversity as the data employed in our analysis span many growing seasons. We have a large diversity of species (see table 3) in our dataset. A total of 64 species mixtures (see in appendix) in 46 sites were examined in different crop diversification in the context of various social and environmental factors. The following figure shows different practices and their LER values after analyzing.

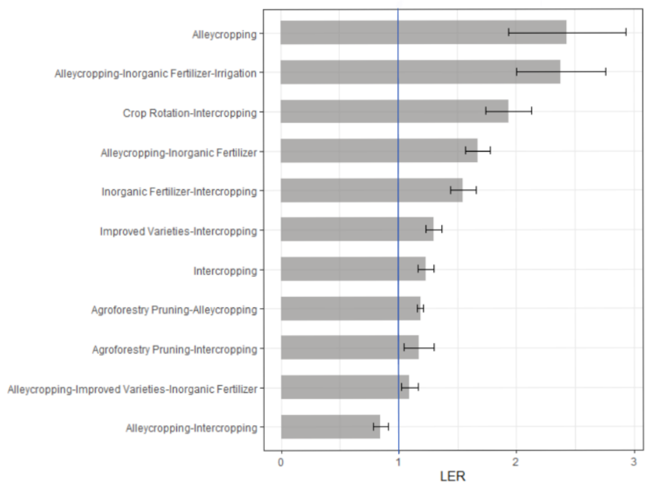

Fig 2 *Practices with associated LER and their errors*

All agronomic practices were carried out according to technical recommendations. Land equivalent ratio values in Fig.2 and Table 2 clearly indicated that all values obtained under the treatment imposed are greater than unity showing the yield advantage as compared when each component was grown alone except for the last practice Alleycropping-Intercropping indicating the yield disadvantage because of the value of the LER value less than unity. High productivity has been verified in four studies with alleycropping because of their high values of LER: Residues-Maize, Residues-Cowpea; Gum Arabic-Roselle or Hibiscus (Fibre), Gum Arabic-Sorghum, Gum Arabic-Sesame Seed; Fodder (Trees)-Pepper (Seed); and Maize in Kenya, Sudan and Tanzania. We observe an increase of 4% of this LER value when using alleycropping-Inorganic Fertilizer Irrigation. Alleycropping Increases Land Use Efficiency and allows famers to effectively use available resources and yield more benefits. Alleycropping systems were in general higher than the corresponding monocultures across the alley cropping period, increased tree yield and show a higher LER. It also presents an advantage in terms of soil and water conservation with less soil loss and runoff. These are some reasons why this agroforestry practice where trees are planted in rows, creating alleyways for cultivating agricultural crops during the early years of tree growth (Gold M et al. 2009) has high Land equivalent ratio which is even higher when applying fertilizers. (Gruenewalda et al. 2007) also confirmed that the minimum LER for the alley cropping system should be above one, which would reflect a positive synergistic or neutral mutual relationship between trees and crops. The following table is showing the general picture of the analysis at the practice level. The highest number of studies (29) has been carried out with intercropping practice on 35 sites with 405 observations that give an average value of LER 1.25.

Table 2 *General picture of the analysis at the practice level. Observations represent the number of rows of data for a specific practice name. Studies = no. studies (publications). Sites = no. of geographic locations. LER=weighted mean of the Land Equivalent ratio. RR.pc.jen = percent change based on RR with correction for Jensen inequality*

Practices Name	Observations	Studies	Sites	LER	RR.pc.jen
Agroforestry Pruning-Alleycropping	36	1	1	1.18	17.2179
Alleycropping	49	4	4	2.28	114.6803
Alleycropping-Improved Varieties-inorganic Fertilizer	9	1	1	1.09	8.0058
Alleycropping-Inorganic Fertilizer irrigation	10	1	1	2.38	116.2781
Alleycropping-Inorganic Fertilizer	2	1	1	1.67	78.7735
Intercropping	406	29	35	1.25	13.4061
Inorganic fertilizer intercropping	92	5	6	1.47	51.2642
Improved Varieties-intercropping	23	2	3	1.27	29.2799
Crop Rotation Intercropping	27	1	3	2.04	89.8122
Agroforestry Pruning intercropping	16	1	1	1.17	8.5363
Alleycropping-intercropping	7	1	1	0.80	-16.3940

M. Abbas et al., 2011 obtained a maximum LER value of 4.65 with the most productive mixtures with sesbania and Rhodes grass. They demonstrated that the introduction of nitrogen-fixing trees into agroforestry and silvo-pastoral systems contribute to sustainable agriculture. They achieved this result by building up, restoring, and maintaining soil fertility, and fuelwood production. Sesbania performs better in particular when intercropped with Sudan grass sandy soil conditions. (Charles Midega et al., 2014), (T. Reyes et al., 2009) and (Kamal Fadl, 2013) respectively obtained LER value of 4.80 with Desmodium intortum-Maize, 3.92 with Black Pepper-Grevillea robusta, 3.80 with Acacia-Sesame. They all used Alleycropping on sandy soil with the same number of replications. Other factors affecting LER are summarized in (table 5).

Intercropping increases crop yield by facilitative plant-plant interactions. When Intercropping maize and bean with okra (2 and 3-species combinations) at different plant densities (high and low), we see the variation of the yield and so, the LER. The highest value is obtained for high density of beans and the high density of Okra (Singh, 2017). So, we observe that the LER is affected by the plant density. The fertility status of soils increases the performance of crops and

Table 3 Important *factors affecting LER with the maximum value of LER obtained*

Practices Name	Species	Sites	Description	Soil texture	Mean annual temp	Mean annual precipitation	Authors	LER
Intercropping	Common Bean-Okra	IITA, Yaounde	high density of bean and high density of Okra	-	23.2	1612	Singh 2017	0.88
Intercropping	Butter Bean-Maize-Yam	FUT Teaching and Research Farm, Owerri	Yam-maize-African Yam bean	-	25.6	2339	Ibeawuchi IC. 2008	0.98
Intercropping	Groundnut-Rice	IRAD, Nkolbisson	RG Rice	Clay Loam	23.2	1612	Mballa 2017	0.98
Intercropping	Maize-Soybean	Nampula	Maize + 8N..Soybean 8N	Sand	23.8	1148	Tsujimoto 2015	0.86
Agroforestry Pruning-Alleycropping	Agroforestry Residues-Maize	KARI, Katumani (ICRAF Machakos)	Intercropping with Leucaena hedge - maize crop to land occupancy ratio of 15:85	sandy loam	20.8	632	Jama BA., 1995	1.49
Alleycropping	Agroforestry Residues-Maize	KARI, Katumani (ICRAF Machakos)	Agroforestry	sandy clay loam	20.8	632	Lott JE. 2000	1.5
Improved Varieties-Intercropping	Common Bean-Maize	Haramaya University	Maize + TY3396 - 12 improved intercrop	-	20.5	921	Taddesse G. 2007	1.66
Intercropping	Finger Millet	Bambey	Millet inter>>Cowpea upright inter	-	27.28	487.83	Trail 2016	1.55
Improved Varieties-Intercropping	Cowpea-Maize	Sapu	Tied ridges sole cowpea Tied ridges relay 31 Days After Maize Planting	loamy sand	28.2	701	Wright JP. 1991	1.44
Inorganic Fertilizer-Intercropping	Cowpea-Pearl Millet	ICRISAT, Niamey	millet-cowpea intercrop at 2 WAMP 1.62	fine sand	28.6	508	Reddy KC. 1992	1.62
Intercropping	Cassava-Melon	FUNAAB, Abeokuta	20/9 cassava - melon	sandy clay	25.5	1248	Olasantan FO. 2007	1.75
Intercropping	Common Bean-Maize	Mecha..South Achefer	maize+bean single 128,20-CB..maize+bean single 128,20- Mazie	Clay	19.7	1460	Alemayehu 2017	1.3
Intercropping	Common Bean-Maize	University of the Free State, Bloemfontein	2nd sowing with intercropping	-	16.7	515	Tsubo M. 2003	1.58
Intercropping	Cowpea-Maize	Ikuwala	Intercrop	-	20.4	716	Vesterager JM. 2008	1.18
Intercropping	Cowpea-Maize	Misamfu ARS (mufulira soil)	Maize + bean intercrop 50/50	sandy clay	20.6	1241	Siame J. 1998	1.67
Intercropping	Cowpea-Pearl Millet	Lemnogo..Ramdolla..Tibtenga	Manure + cowpea..Manure + Millet	-	-	-	Sanou 2016	1.95
Intercropping	Cowpea-Sorghum	UKZN Ukilinga Research Farm, Pietermaritzburg	Intercrop Cowpea- Rainfed..Intercrop sorghum - Rainfed	Clay Loam	24.75	775	Chimonyo 2016	1.97
Intercropping	Groundnut-Maize	ARC, Ismailia	Maize intercrop..Peanut intercrop	Sand	21.4	21.3	Metwally 2018	1.3
Intercropping	Lablab	Zwelisha, Bergville	Lablab tram..Maize tram	-	14.1	1049	Mthembu 2017	1.59
Intercropping	Maize-Soybean	Adigudem	Four Till Maize - 2015..Four Till SB - 2015	Clay	22.2	534	Tsegay. 2018	1.11
Agroforestry Pruning-Alleycropping	Gum Arabic-Sesame-Sorghum	Ad-Damazin ARS	A.seneal 5 x 5 sesame / sorghum	-	28.3	682	Raddad EY., 2007	2.29
Crop Rotation-Intercropping	Cassava-Cowpea-Maize-Soybean	Kwadaso	S1 Ankra	sandy loam	26.2	1196	Dapaah HK., 2003	2.8
Inorganic Fertilizer	Maize-Pigeon Pea	Ruaca	Maize - pigeonpea.within row + 20P + 0N	-	21.4	1208	Rusinamhodzi L., 2012	2.4
Inorganic Fertilizer-Intercropping	Common Bean-Sorghum	ISAR, Butare	Sorghum - bean (AR) + 33N	silty loam	19.9	1199	Kavamahanga F., 1995	2.12
Intercropping	Cassava-Groundnut-Maize	RSU Teaching & Research Farm, Port Harcourt	20000 cassava + maize + groundnut	-	25.6	2265	Zuofa K., 1992	2.51
Intercropping	Cassava-Okra	FUNAAB, Abeokuta-Field A	Cassava inter Odongbo..Okra intercrop	Loamy Sand	25.5	1248	Salau., 2014	2.14
Intercropping	Cotton-Wheat	ARC, Gharbia Governorate	6 Cotton 100%..6 Wheat 100%	-	22.0	47.3	Galil. 2015	2.65
Alleycropping	Fodder Tree-Pepper	Shebomeza	T1 Grev + BP	-	24.7	1679	Reyes T., 2009	3.92
Alleycropping	Gum Arabic-Sesame	El Obied	Acacia - sesame	sandy	27.3	336	Fadl KEM 2012	3.8
Alleycropping	Maize	ICIPE, Mbita Point	desmodium..Maize intercrop	-	23.6	1157	Midega 2014	4.8
Alleycropping-Inorganic Fertilizer-Irrigation	Barley-Fodder Tree	SCU Experimental Farm, Ismalia	Sesbania + barley + 75N	sandy	21.4	28	Abbas M 2001	4.65

then, the productivity as it has been demonstrated by (Onweremadu et al., 2008) when studying the intercropping of yam, maize, cassava, African Yam, and bean. In addition, The LER increases were also achieved using resources that are available to small-scale producers in the region such as seeds and mulch and did not require the addition of fertilizer inputs. Increasing ground cover through mulching of millet increases soil moisture and land equivalent ratio compared to millet grown with no additional ground cover (Abaye et al., 2016).

Wright JP et al. (1991) calculated an LER of 1.44 (in Gambia) using relay intercropping and obtained the highest value 31 days after maize planting, Vesterager JM et al. (2008) calculated an LER of 1.18 (in Tanzania), while

Rusinamhodzi L et al. (2012) calculated an LER of 2.4 (in Mozambique), in each of their Maize-Cowpea systems, respectively. Midega et al. (2014) demonstrated an LER of 2.50 for Maize-Cowpea systems in Kenya's ICIPE, Mbita Point. They all have different factors: site, soil, location, density, temperature, precipitation, etc… Even though they are using the same species, it is difficult to compare these values as each study has unique planting densities and inputs. The highest yield increases were observed in the treatments where cowpea and maize were intercropped followed by the treatment Maize-pigeonpea within row + 0P + 0N in Vunduzi, Mozambique.

Increases in millet yields were high enough to exceed those of the combined millet-legume yields of the intercropping treatments with an LER of 1.55 in the mulched treatment at Bambey, greater than any of the LER's calculated for the intercropping treatments (Abaye et al. 2016). The field experiments were implemented without the use of fertilizers. They demonstrated that adopting mulching or intercropping practices, in their study in Senegal potentially increases LER.

Selective soil properties in the surface are also an important factor affecting the land equivalent ratio. This has been demonstrated by Reddy et al. (1992) when intercropping millet-cowpea, the selected appropriate fertilizers with specific soil PH to show that soil fertility has effects on the productivity and then the land equivalent ratio without forgetting to take into account that generally in Niamey, Niger, millet is grown on infertile sandy soils in association with cereals such as sorghum and/or with legumes such as cowpea or groundnuts (Reddy et al., 1990). Likewise, (Raddad et al. 2007) showed that the soil water content is important for soil water storage and crop growth. Before sowing of an annual crop plays an essential role in crop growth and LER. So, increasing the soil water storage before sowing could contribute to crops developing larger and deeper root systems. They obtained an LER value of 2.29 using Agroforestry Pruning-Intercropping with Acacia Senegal 5 x 5 sesame/sorghum setting.

Another important factor is planting arrangement which has been mentioned in the study of (Alemayehu et al., 2017). They recorded the highest LER for the single row intercrop planting arrangement with 128/20 kg N/P/ha among the other eight arrangements. Maize-common bean intercropping was 20% more productive as measured from LER in the 128/40kg N/P/ha treatment applied. The 128/20 kg N/P/ha arrangement applied on maize rows was the most profitable relative to sole crop maize and other intercrops. Optimizing N requirements of common bean can maximize the productivity of maize-common bean intercrop since their study indicated high common bean demand for N in a maize-common bean intercrop system.

Plant density, row orientation, sow date, fertilizer, radiation, and water use efficiencies (RUE and WUE) have been mentioned to be factors affecting LER by (Tsubo et al. 2003). The higher LER was obtained on the 2nd sowing with intercropping for the treatment of common Bean-Maize in the plant density trial and sole cropping + basal fertilizer 254N + 67P + 33K for the control. Air temperatures were normal, and rainfall was below normal in all growing seasons. The total land equivalent ratios showed yield and growth advantage of intercropping as reported by (Mukhala et al. 1999), the yield advantages in maize-bean intercropping over the sole cropping.

In most cereal/legume studies, an increase in the level of nitrogen increased LERs (Siame et al. 1998). We can observe it with the mean land equivalent ratio for maize and beans 1.27, 1.36, 1.41, 1.55, and 1.69 in four intercropping systems at five nitrogen application regimes (0, 30, 60, 90, and 120 kg N/ha). The highest value has been obtained with Maize + bean intercrop 100/50 treatment. When there is no nitrogen applied, over the four intercropping treatments, the maize LER in intercropping averaged was less than unity.

The land equivalent ratio has also been used to evaluate crop performances. (Sanou et al. 2016) calculated the LER value for each year and each crops association with four fertilization treatments (NPK, manure, NPK+ manure, and control) using cowpea and millet. Among their 32 experimental designs showing fertilizer applications and crop combinations repeated in three sites in Burkina Faso, the highest value of LER was obtained for the combination Manure+cowpea intercropped with Manure+Millet in Tibtenga, Burkina Faso. Variation of land equivalent ratio occurred for different varieties of intercropping.

Improved water availability is sometimes related to better LER. This is observed in the study of (Chimonyo et al. 2016) during the 2013/2014 growing season, intercrop systems grown under deficit irrigation resulted in lower LER (38%) relative to 2014/2015. Due to the improved water availability in 2014/2015, the comparison of LER of intercrop across the two growing periods, that average LER was lower (7.68%) in 2013/2014. Intercropping cowpea with sorghum was more productive than intercropping it with bottle gourd, in average. The demonstrated that cowpea and bottle gourd were able to improve soil water availability by minimizing soil evaporation. Cowpea was able to improve nutrient availability for sorghum and improve root function which help for effective use of water.

Mixing different species, associated with combinations of different plant traits (plant height, photosynthetic mechanisms, growing season) is a form of functional complementarity that might increase LER in intercrops (Cong et al.,2014, 2015). In the study of (Y Yu, 2016), he developed a functional-structural plant model to investigate the mutual action between spatial and temporal complementarity and plant traits in mixed plant systems and he demonstrated that complementarity of light use in time and space determine the productivity of species mixtures. The early sown plants have the advantage from later sowing of the late sown plants. He emphasized an important and positive interaction between the amount of N applied to the intercrop and temporal niche differentiation (TND) and indicated the advantage when high levels of nutrients are provided. The effect of temporal niche differentiation on LER is positive and increases the value of LER for an increase of TND for every application of 100 kg N/ha.

Conclusion

The present study has demonstrated that cropping systems differed in their LER among the different environments. Among studies, a large variation of LER has been observed and many factors could contribute to this variation including plant density, the fertility status of soils, seeds, increasing ground cover, the duration after planting, fertilizers, soil properties in the surface, planting arrangement, the soil water storage, sow date, radiation use efficiency, water use efficiency, crop species combination associated with combinations of different plant traits (plant height, photosynthetic mechanisms, growing season), the complementarity of light use in time and space. Land equivalent ratio values obtained under the treatment imposed are greater than unity showing the yield advantage as compared when each component was grown alone except for Alleycropping-Intercropping. High productivity has been verified in four studies with alleycropping because of their high values of LER. Alleycropping systems were in general higher than the corresponding monocultures across the alleycropping period, increased tree yield and show a higher LER especially when applying fertilizers. It has been confirmed by many studies that the minimum LER for the alleycropping systems should not be below one, which would reflect a positive synergistic or neutral mutual relationship between trees and crops. These values of LER above one are also observed with Crop Rotation-Intercropping, Improved Varieties-Intercropping, Alleycropping-Inorganic Fertilizer. Our Meta-Analysis revealed that species diversity and intercropping options have been mentioned in many studies as the main factors affecting LER (Naeem et al., 1994; Tilman et al., 1996; Van School, 1998; Loreau and Hector, 2001; Tilman et al., 2001; Van Ruijven and Berendse, 2003; Cardinale et al., 2007). In the most complete review of the subject, Lamberts (1980) cited many reasons for intercropping: increasing productivity/yield advantage, better use of available resources, reduction in damage cause by pests, socio-economic and other advantages. Under a better usage of available resources, we also have socio-political factor (land), economic factor (labor), agronomic factor (water and nutriments). This study has helped us to identify factors that can be used to maximize the Land equivalent ratio in order to maximize the yield and productivity.

Acknowledgments

We wish to thank the African Institute for Mathematical Sciences (AIMS) and the International Council for Research in Agroforestry (ICRAF) for providing financial support and facilities.

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