



Competitive and complimentary effects of *Artemisia (Artemisia annua L.)* on Maize (*Zea mays L.*) intercrops in a sub-humid ecozone of Western Kenya

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Abstract

An agroforestry (AF) study at Maseno, Western Kenya investigated some component interactions in a shrub-based intercropping system of artemisia (*Artemisia annua L.*) and maize (*Zea Mays L.*) for two consecutive rainfed seasons, by evaluating yield attributes and patterns from among different spacing regimes using the competitive ratio (CR) and % Land Use Efficiency (LUE). The experiment had 8 treatments (T₁ to T₈) laid out in a randomized complete block design (RCBD) with 3 replications. The treatments had a significant effect (P < 0.05) on plant biomass of maize and LUE. There was also a significant effect (P < 0.05) on CR of artemisia against maize among the intercrops. Artemisia as an *Asteraceae* is 1.3 (or 30%) more competitive than maize (*Graminae*), when the two component crops are grown in association with optimal spacing. LUE values higher than 100% indicate the presence of facilitative component interactions or complementarity among the crop components of T₃, T₄ and T₆. It is concluded that by varying spacing regimes and hence plant densities for biomass and leaf yields of maize and artemisia respectively, profitable artemisia+maize intercropping require that farmers apply spatial arrangements in which complementarity effects on net yields equal or exceed competitive abilities of artemisia. In so doing, the spacing regimes of T₄ = Artemisia 0.75 m X 0.75 m; Maize 0.9 m X 0.75 m and T₆ = Artemisia 0.9 m X 0.9 m; Maize 0.9 m X 0.75 m are recommended for the purpose.

Keywords: agroforestry, competitive ratio, land use efficiency, artemisia, maize

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Introduction

Intercropping as an Agroforestry (AF) practice is a form of multifunctional agriculture (Pandey, 2007) in which food crops are cultivated on the same land management unit as shrubs in various forms of spatial arrangement. Establishment of agroforestry systems is one of the options of reducing deforestation and increasing the terrestrial C sinks, where variations in soil and climatic conditions results in significant differences in C stocks (Kaonga and Bayliss-Smith, 2010). Generally,

intercropping systems in the sub-humid tropics are part of a continuum of landscapes for interrow crops for intensive home gardens (Abebe, 2005), in which the shrub component can stay in the field for a prolonged fallow period. The term "Fallow" in this study refers interchangeably to agricultural land lying idle as a means 'to rest tired soils' before a subsequent season, or the actual plant species to be grown; and also the short duration of time in the intervening periods when such land is idle. In addition, non-legume shrubs belonging to the *Asteraceae* family like

artemisia may provide vital lessons for further development of improved fallows (Sanchez, 1999). Fallows in general can provide great opportunity for various component interactions that include both competitive and complementarity effects on plant growth, and this may be manipulated to enhance productivity of AF systems. For purposes of on-farm crop biodiversity conservation and value addition to subsistence farming, maize (*Zea mays* L.) is a staple food crop in all agro-ecological zones (AEZ) of Kenya; While artemisia (*Artemisia annua* L.) is a medicinal shrub species recently introduced for commercial cultivation in the region (EABL, 2005). Artemisia has aromatic properties, and qualifies as an enriched fallow species that also exhibits a potential for short season ratooning (Chumba et al., 2012). When artemisia and maize are intercropped, these attributes may offer enormous capacity to optimize yield of maize grain and artemisia leaf while minimising field operations and lowering production costs. Given the small average farm sizes of 0.6 ha in western Kenya that is below the FAO recommendation for subsistence farming (FAO 1999), multifunctional agriculture systems like intercropping are hence a potential option for land use efficiency in fallows to enhance livelihoods in the region.

In multifunctional agriculture as in AF intercropping systems there are various component interactions that affect on-farm productivity. According to Dhima et al. (2007), competitive component interactions will have a significant impact on the growth rate hence yield of the different species used in intercropping. Competition can occur between the same plant species, called intraspecific competition, or between different species, called interspecific competition (Van der Meer, 1989). Interplant competition may not always result in a poor performance

of the intercrop, where the advantages of an intercropping system include increase in production per unit area of land despite the competition for space and growth nutrients. According to Cadisch et al. (2002) mixing species with compatible and complimentary root and/or shoot growth patterns leads to a more diverse system and may also maximise above and below ground growth resources' utilization. In this respect, Sobkowiez (2006) further reports that two commonly used intercropping strategies entail planting a deep-rooted crop with a shallow-rooted crop, or planting a tall crop with a shorter crop that requires partial shade.

Ultimately, crop yield variability comes from complex interactions between the environment, spacing, management, progenitors and abiotic factors that occur across a field (Baumann et al., 2001) of intercrops. AF systems where artemisia and maize are grown in association should thus create component interactions between at least two individual biotic or abiotic components that may either reduce or increase the vigour of the system. In sub humid zones on acid soils competition between shrub-crop intercrops for light, nutrients and moisture can be very severe due to the effect of shading (Lawson and Kang, 1990), where significant crop yield reductions with increase in distance from the shrub rows have been reported (Chirwa et al., 2007). Since water and nitrogen are critical nutrients for plant growth and productivity in crop components of fallow systems (Hartemink et al., 2000), competition can also be more severe in degraded sloppy areas of western Kenya with erratic rainfall patterns. Okalebo et al. (1999) and Ferreira et al. (2005) incorporated root stumps from previous harvests of maize and artemisia respectively to enhance soil organic matter content of subsequent monocrop stands.

In Western Kenya, where AF is almost synonymous with intercropping maize with fertilizer trees/shrubs for improved fallow systems, the role of fallow periods in nutrient recycling is well documented (Cadisch et al., 2002; Ståhl et al., 2005). A short 45th day fallow period was found to be one of the determining factors for yield advantage in sequential maize+artemisia intercrops in a sub-humid AEZ (Chumba et al., 2012). It may thus be worth to presume that there could be a certain threshold duration of time within which crop residues from a previous harvest is beneficial to a subsequent intercrop stand and general farm productivity. This should be manifested in Area x Time Equivalent Ratio (ATER) values (Hiebsch and McCollum, 1987) of the subsequent cropping season, since yield variations in AF intercropping systems may be attributable to complementarity and differential use of growth resources by the component plants over time.

Complimentary component interactions have been documented by Sunwar (2003), who reported the use of *Artemisia* sp. as a natural pesticide in Nepalese home gardens. Through such component interactions, *Artemisia* sp was also found to suppress some weeds by use of allelopathy (Lydon et al., 1997; Mekky, 2008; Darrouzet-Nardi et al., 2008). AF intercropping systems incorporating maize and artemisia crop components could thus provide an eco-friendly approach for controlling weed incidence through minimal or non-use of synthetic herbicides as a good agriculture practice (GAP). This will ensure the least possible impact on the natural environment and yielding a medicinal product that can be accurately traced from the field where it is grown to the consumer (WHO, 2003). However, as a function of on-farm productivity and land use efficiency, the potential benefits accruing from

intercropping artemisia and maize on yield of both crop components in regard to competitive or complimentary abilities is yet to be documented.

Several concepts and/or indices have been employed over the years by diverse scholars to evaluate component interactions for competition and potential benefits, losses or efficiency of various intercropping systems. Rao (2002) successfully used the biological land use efficiency (LUE) to determine which row spacing was more efficient in the use of land, area and time for optimal yield of biomass and essential oil of *Pelargonium* sp intercropped with corn mint (*Mentha arvensis* L). Willey and Rao (1980) demonstrated that the competitive ratio (CR) could be useful in comparing the competitive ability of different crops and determine what competitive balance between crop components is most likely to give maximum yield advantages. CR is thus a measure of relative interspecies competition that indicates the number of times by which one component crop is more competitive than the other (Willey and Rao, 1980).

Apart from intra-specific competition, plants compete with individuals that are to some extent different while their resource requirements and their abilities for resource acquisition are not necessarily the same (Mkamilo, 2004). Furthermore, the CR represents the ratio of individual LERs of component crops and takes into account the proportion of the crops in which they are initially sown (Putnam et al., 1985). Since the CR targets a range of growth resources for competition, it may hence be applicable interchangeably in Additive Series and Replacement Series of intercropping (Fukai and Trenbath, 1993) targeting interplant competition for one specific growth resource. There is however little scientific evidence from sub humid AEZ on interactions between inter-plant

competition of shrubs and food crops; but the biological merits of intercropping (Van Noordwijk et al., 1999) makes it a suitable farm practice to enhance crop biodiversity, AF system productivity and land use efficiency for smallholder farmers. As a supplementary effect of component interactions, an AF system eliminated the need for contact herbicides due to foregone variable costs of labour associated with post-emergent weeding in artemisia+maize intercrops (Chumba et al., 2012). Managing the factors that affect attainment of food security from maize and farm incomes from artemisia therefore include the opportunities presented by manipulating component interactions in AF systems.

Materials and Methods

The experiment was carried out during the period from September 2009 to August 2010, relying on rainfall precipitation of two consecutive seasons at Maseno University farm, which experiences a seasonal semi-deciduous moist Agroforest climate (FAO, 1978). The agronomic practices for maize+artemisia intercrops, and respective sole crops (Okalebo et al., 1999; Ferreira et al., 2005) included a short fallow period of 45 days in between the two seasons. There were eight treatments, laid out as a randomized complete block design (RCBD) in 3 replications. Each plot replica size measured 6m x 4m (24 m²) including two control plots of pure stands for each of maize and artemisia. The intercropping pattern was designed in such a way as to minimize competition for growth resources by manipulation of spatial arrangement. These plant spatial arrangements were in 'Additive series' to result in a constant maize plant density in all treatments but varying artemisia population according to the method of Fukai and Trenbath (1993). The treatments were designed as follows (Chumba et al., 2012):

- T₁ = *Artemisia* 1m X 1 m; Maize 0.90 m X 0.75 m;
 T₂ = *Artemisia* 1 m X 0.75 m ; Maize 0.90 m X 0.75 m ;
 T₃ = *Artemisia* 1 m X0.9 m ; Maize 0.90 m X 0.75 m;
 T₄ = *Artemisia* 0.75 m X 0.75 m ; Maize 0.9 m X 0.75 m ;
 T₅ = *Artemisia* 0.9 m X 0.75 m ; Maize 0.9 m X 0.75 m ;
 T₆ = *Artemisia* 0.9 m X 0.9 m ; Maize 0.9 m X 0.75m ;
 T₇ = *Maize* 0.90 m X 0.75 m (Pure Stand);
 T₈ = *Artemisia* 1 m X 1 m (Pure Stand);

After the first weeding and canopy closure of artemisia in all treatments, only maize pure stand was subjected to 2nd weeding out of necessity because all artemisia treatments did not harbour any subsequent weeds to warrant additional labour input costs of weeding. Above-ground plant biomass of both maize and artemisia was determined at harvest to mimic farmers' practice (Chumba et al., 2012) from an area of 24 m² at harvest and extrapolated to production ha⁻¹. Artemisia was severed at the root apex and the harvested plants placed in brown paper bags after sun drying on black polythene sheets, after which they were weighed using an electronic weighing balance (Denver instrument model XL -31000) at Maseno botanical gardens. A similar treatment was also done for grain maize and biomass yields in which measurement was done with dry whole stalks severed at the root apex. Artemisia leaf and maize grain were the yield attributes used in determining Land equivalent Ratios (LER). The LER was computed by the equation suggested for trees or shrub+food crop mixtures by Rao and Coe (1992).

$$LER = C_i/C_s + A_i/A_s \quad (1)$$

Where, C_i = Maize crop yield under intercropping; C_s = Maize crop yield under sole cropping; A_i = Artemisia yield under intercropping; and A_s = Artemisia yield under sole system.

Measurements to demonstrate the existence or not of competition by comparing the CR among the intercrops in each treatment was calculated following the method of Willey and Rao (1980):

$$CR_{\text{maize}} = (LER_{\text{Maize}} / LER_{\text{Artemisia}}) \times (Za / Zm), \quad (2a)$$

$$CR_{\text{Artemisia}} = (LER_{\text{Artemisia}} / LER_{\text{Maize}}) \times (Zm / Za) \quad (2b)$$

Whereas, LER_{Maize} is the Partial land equivalent ratio (LER) for Maize, $LER_{\text{Artemisia}}$ is the partial LER for Artemisia in the crop mixture. Zm and Za are the proportions of maize and artemisia in the mixture respectively.

The biological Land Use Efficiency (LUE) for each treatment was calculated by averaging the sum of LER and ATER from the maize + artemisia intercrop according to the method of Rao (2002), indicating which cropping pattern was more efficient in the use of land, area and time for optimal yield :-

$$LUE = (LER + ATER)/2 \quad (3)$$

Where, LER is as defined in equations (1) above and ATER is the Area-Time Equivalent Ratio as described at (4) below from the second LR season. The total duration of the intercrop system used was 300days including a 45-day fallow period between the two cropping season. Substituting for artemisia and maize interchangeably, the equation of Hiebsch and McCollum (1987) was used:

$$ATER = \sum_{i=1}^n \frac{t_i^s}{t_1} (Y_i^I / Y_i^S) \quad (4)$$

Where, Y_i^I and Y_i^S are the yield of crop I in intercropping and sole cropping, respectively and $n=2$ (or the total number of crops in the intercropping system); t_i^s is

the growing period of crop I in sole cropping and t_1 is the total duration for the intercropping system including fallow period. The data collected on CR, maize biomass, LER, ATER and LUE was subjected to analysis of variance using the COSTAT version 6.4 statistical computer package. The treatment means were separated using the least significant differences (LSD) test at 0.05%, while homogeneity of variances was verified by Bartlett's test.



Plate 1. Artemisia + Maize Intercrop T3 at Physiological Maturity



Plate 2. Artemisia+ maize Intercrop T6 after 2 months (before 2nd Weeding)

Results and Discussion

General

The data on land use efficiency (LUE), biomass yields and competitive ratio (CR) obtained from the intercropping system of maize + artemisia in different spacing regimes is presented in Tables 1 and 2 respectively.

Biomass yield

Since lower biomass yields in intercrops are usually associated with interplant competition for growth resources, these results may thus suggest that the spacing regimes tested did not constitute crowded conditions to effect negative competition for light and other growth resources. However, the higher yields of maize observed in LR compared to the SR may have been occasioned by higher precipitation levels experienced in LR relative to SR. Besides being a varietal trait maize and artemisia biomass yields is also a reflection of nutrient availability, management level and favourable prevailing weather. The treatments had a more significant effect in the LR than SR on plant biomass of both artemisia and maize apart from the control of each intercrop, suggesting that the LR may be more ideal than the SR for these intercrop arrangements when plant biomass is the preferred attribute for yield advantage; But this aspect needs authentication through further testing for several seasons with respect to precipitation levels and patterns. The facilitative component interaction between the intercrops observed in T₃ maize may be attributable to less crowding, as the lowest plant density stand which enhanced a suitable microenvironment for optimal growth conditions. The effect of positive component interaction between the intercrops was more pronounced in T₃ maize, to result in high biomass yields of 2.78 t ha⁻¹. The highest biomass yield from T₇ maize at 3.85 t ha⁻¹ is attributable to the effect of 'Niche differentiation' in favour of maize as was reported by Mkamilo (2004). The high biomass yields of artemisia obtained from T₅ (8.98 t ha⁻¹), T₄ (9.67 t ha⁻¹) and T₆ (7.03 t ha⁻¹) apart from the control plot of T₈ with 9.65 t ha⁻¹ may have been possibly due to greater spatial

complementarity. These spacing regimes represent plant proportions and densities that optimise total biomass yield through facilitative component interactions that occur in intercropping systems. Complementarity of resource use may also have occurred through synergistic effect of applying commercial fertilizer to maize intercrops, as demonstrated by the significant effect of spacing ($P < 0.05$) on biomass yields (Table 2).

The Competitive Ratio (CR)

The treatments had a significant effect ($P < 0.05$) on the Competitive Ratio (CR) of artemisia against maize among the intercrops during both seasons (Table 2). T₃ exhibited the highest mean CR at 1.75 while T₁ had the Lowest CR at 0.85 and were statistically different from the control. T₁ maize ($CR_{SR}=1.5$, $CR_{LR}=0.9$) had a higher CR than artemisia ($CR_{SR}=0.67$, $CR_{LR}=1.03$). The CR index determines the degree to which one crop competes with the other in an intercropping system and measures competitive changes within a given crop combination (Willey and Rao, 1980); So that if $CR < 1$, there is a positive benefit for maize relative to artemisia; and if $CR > 1$, there is a negative benefit to the secondary crop relative to the main crop (Putnam et al., 1985). On average, artemisia was 1.3 (or 30%) more competitive than maize during both cropping seasons in this study. It is noteworthy that maize exhibited significantly lower competitive ability than artemisia, even though it had the highest intercropping densities among the treatments and was provided with an early competitive advantage by being sown first semi-sequentially. It is therefore expected that artemisia would outcompete plant species from members of the grass family including weeds when grown in association. Chumba et al. (2012) demonstrated over 50% reduction in

Table 1. Effect of spacing Maize and Artemisia on Land Equivalent Ratios (LER), Area+Time Equivalent Ratio (ATER) and % Land Use Efficiency (LUE)

⁺ Treatment	LER	ATER	LUE %
T ₁	1.36a	0.8bc	95.4ab
T ₂	1.39a	0.9ab	98.7ab
T ₃	1.41a	0.95ab	101.1a
T ₄	1.41a	1.0a	100.8a
T ₅	1.35a	0.9ab	96.7ab
T ₆	1.49a	1.0a	106.3a
T ₇	1.00b	0.35d	67.5d
T ₈	1.00b	0.5c	75cd
CV (%)	6.5	2.66	13.00%
LSD _{0.05}	14.5	13.08	4.36
⁺ Spacing	*	*	*

(Mean values in a column followed by dissimilar letter (s) indicate differences at 0.05 (*) level of significance)

- ⁺ T₁ = Artemisia 1 m X 1 m ; Maize 0.90 m X 0.75 m ; T₂ = Artemisia 1m X 0.75 m ; Maize 0.90 m X 0.75 m
T₃ = Artemisia 1 m X 0.9 m ; Maize 0.90 m X 0.75 m ; T₄ = Artemisia 0.75 m X 0.75 m ; Maize 0.9 m X 0.75 m
T₅ = Artemisia 0.9 m X 0.75 m ; Maize 0.9 m X 0.75m ; T₆ = Artemisia 0.9 m X 0.9 m ; Maize 0.9 m X 0.75 m
T₇ = Maize 0.90 m X 0.75 m (Pure Stand) T₈ = Artemisia 1 m X 1 m Artemisia (Pure Stand)

Table 2. Effect of Spacing Maize and Artemisia on Biomass Yields, Competitive Ratios (CR) and % Land Use Efficiency (LUE)

Treatment ⁺	InterCrop	Biomass yields(t/ha)		Competitive Ratios	
	Population (24m ²)	Maize	Artemisia	CR _{Artemisia}	CR _{Maize}
T ₁	85	2.38bc	7.36bc	0.85c	1.20a
T ₂	78	2.10c	7.29bc	1.47b	0.69bc
T ₃	74	2.78bc	5.39d	1.75a	0.52bd
T ₄	90	2.35bc	9.67a	1.30b	0.76bc
T ₅	90	2.25bc	8.975a	1.16b	0.95b
T ₆	85	2.38bc	7.08c	1.24b	0.80c
T ₇	50	3.85a	-	-	0e
T ₈	35	-	8.75ab	0d	-
CV%	-	19.96	16.45	19.30	26.49
LSD _{0.05}	-	0.31	0.81	0.385	0.29
Spacing	-	*	*	*	*

(Mean values in a column followed by dissimilar letter (s) indicate differences at 0.05 (*) level of significance)

- ⁺ T₁ = Artemisia 1 m X 1 m ; Maize 0.90 m X 0.75 m ; T₂ = Artemisia 1 m X 0.75 m ; Maize 0.90 m X 0.75 m
T₃ = Artemisia 1 m X 0.9 m ; Maize 0.90m X 0.75 m ; T₄ = Artemisia 0.75 m X 0.75 m ; Maize 0.9 m X 0.75 m
T₅ = Artemisia 0.9 m X 0.75 m ; Maize 0.9 m X 0.75m ; T₆ = Artemisia 0.9 m X 0.9 m ; Maize 0.9 m X 0.75 m
T₇ = Maize 0.90 m X 0.75 m (Pure Stand) T₈ = Artemisia 1 m X 1 m Artemisia (Pure Stand)

variable costs of labour associated with manual weeding in artemisia compared to maize monocrops crops; where no weed emergence and fungal infestation (*Ustilago maydis*)

was observed after first weeding and canopy closure of artemisia stands relative to maize. Artemisia aqueous extracts after value addition should thus provide suitable

Biochemicals for the agriculture industry targeting weed infestation and fungal attack on food crops to further guarantee food security and sustainable farm incomes. Both competition and interplant facilitation occurs in any intercropping system as was reported by Van der Meer (1989). Since complimentary or facilitative component interactions in T₁ resulted in significantly higher maize biomass yields (Table 2), T₁ intercrop arrangement may thus represent a propensity towards facilitative component interactions in favour of maize under this spacing regime, by exhibiting parity in competition with artemisia for growth resources. T₁ intercropping arrangement could hence be more desirable for plant architectural arrangements if maize is to be considered as the main crop in the mixture for optimal yields. This is the opposite of T₂, T₃, T₄, T₅ and T₆ when artemisia is targeted as the main crop. Shahid and Saeed (1997) also used CR values >1.0 to report that lentil (*Lens esculentum*) was a better competitor when sown in association with wheat (*Triticum aestivum*).

In general, the more a competitive ratio of each treatment approached unit value, the more the maize+artemisia intercrop balanced the competition between both species, suggesting further that there is an advantage in maize intercropped with artemisia in single hedgerows of each plant species. This yield advantage is probably due to different above-ground growth habits and morphological characteristics of intercrop components for causing optimal use of growth resources/ factors. The rationale here is that since the two species rely on the growth resource differentially, for example light on account of their variation in growth rate, then facilitative component interactions may be possible. This argument corroborates that of Awal et al. (2007), who report that as CR

approaches unit values intercrop associations effectively counterbalance the competition for growth resources.

In addition, CR is derived from LER and thus represents the proportion of the crops in which they were initially sown. Higher CR values for artemisia therefore suggest that the crop utilised the growth resources more aggressively than maize, despite having been transplanted sequentially. Artemisia T₃ had an exceptionally higher CR value than other treatments, suggesting that this intercropping regime represents a comparatively strong competitive ability for artemisia against maize, and is hence expected to reduce maize yields when grown in association (Plate 1). A similar observation was made by May (1982) while working on green grams (*Phaseolus Aureus*) and bulrush millet (*Pennisetum Americanum*) intercropping. Both competition and complementarity occurred in the maize+artemisia system, suggesting that CR could also be useful in determining what plant density between crop components can give high yield advantages. Since artemisia T₃ had the lowest plant density (Table 2) among all treatments except pure stands, another possible implication of high T₃ CR values is that artemisia crops' in this spatial arrangement had more than ample space for growth and development, and may have concentrated on physiological mechanisms to optimise use of growth resources. Banik et al. (2000) also reported similar trends in competition and recorded depressed intercropping yields of mustard (*Brassica Compestris*) when grown in association with peas (*Vigna unguiculata* L.), lentils (*Lens esculentum*) and grams (*Phaseolus Aureus*) over sole cropping.

Land Use Efficiency (LUE)

The critical value for LUE is 50% for each crop component and 100% for the intercropping system (Rao,

2002). Ideally, the most efficient intercropping should record at least 100% so that the more a spacing regime approaches this value the more efficient it should be. All controls of pure stands recorded significantly lower values than 100%. These results are in general agreement with Scheidegger (2008), that intercropping has at least 30% higher biological efficiency than sole cropping. Logically, LUE values higher than 100% should indicate the presence of complimentary or facilitative component interactions between crop components of the mixture. Furthermore, since ATER is a function of the fallow period employed in this study, the LUE outcome may further suggest that optimum yields per unit area of land can be obtained by starting a new cropping cycle after a short fallow period of 45 days when soil fertility has presumably been restored to a level sufficient enough to sustain a second crop. Similar observations were made by Louise and Tauer (1992). Thus, both complementarity and competitive ability of component crops from this study can form a basis for recommending improved agroeconomic productivity in maize+artemisia intercrops. A similar proposition was made in the ecological and socioeconomic context of maize+sesame intercropping (Mkamilo, 2004). By varying spacing of maize and artemisia, successful intercropping (Plate 2) may require that farmers design efficient systems in which complementarity effects of intercropping on biomass yields exceed competitive effects. Aggregate results suggest that T₃, T₄ and T₆ in this ascending order are superior planting patterns in this study as observed from CR and LUE values. The spacing regimes have greater land use efficiency for respective crop of preference; and have more biological yield advantage which will presumably translate into higher agroeconomic net returns.

Conclusion

This study demonstrates AF intercropping as a space, time and labour dependent form of multi-functional agriculture, for crop diversification to enhance land use efficiency and attain food security. Short fallow periods of at least 45 days annually will lead to intensification of land use and optimize returns from sequential artemisia+ maize intercrops. The CR and LUE indices when used in tandem should provide an improved estimate of the cumulative effects of above-ground component interactions for relative yield advantage of an intercropping system employing short fallow periods. These indices can aid researchers/extension agents in selecting suitable spacing regimes on basis of optimal component interactions and desired level of intensification for recommendation to farmers and other stakeholders. Due to the small average farm sizes and hence a need for intensified land use practices in areas with similar AEZ to western Kenya, a spacing regime of T₄ (*Artemisia* 0.75 m X 0.75 m; *Maize* 0.9 m X 0.75 m) or T₆ (*Artemisia* 0.9 m X 0.9 m; *Maize* 0.9 m X 0.75 m) is recommended for artemisia+maize intercrops depending on desired level of intensification.

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