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RESEARCH PAPER

Yield advantage of maize and artemisia intercrops in a sub-humid ecozone of Western Kenya

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Abstract

A study of intercropping systems in the upper midland agroecological zone (AEZ) of western Kenya sought to evaluate yield patterns of different maize+artemisia spacing regimes as potential practices for enhancing biodiversity, through identification of the most beneficial system component. The experiment was carried out between 2009 and 2010 in two consecutive seasons. 8 treatments were laid out in a Randomized Complete Block Design (RCBD) design with 3 replications. The productivity of these systems was evaluated using Replacement Value of Intercropping (RVI), Cost-Benefit analysis (CBA) and Dominance Analysis (DA). The treatments had a significant effect on RVI ($P<0.05$). Spacing had a significant effect on artemisinin yield ($P<0.05$) in the short rains (SR), and exhibited a high mean of 0.8% in the long rains (LR). The treatments had no significant effect on chlorophyll content of both maize and artemisia ($P>0.05$), but there was a positive correlation between artemisinin and the chlorophyll content of artemisia ($r^2=0.7$) in SR. CBA showed artemisia monocrops to be economically more advantageous than other treatments. Maize+artemisia intercrops exhibited a 60% to 70% more biological and economical yield advantage than maize monocrops under the same management system, using RVI. The identified biological yield advantages did not however translate into substantial economic efficiency and a combined CBA and DA proved only the maize sole crops to be uneconomical, whereby overall system productivity favoured T_6 maize+artemisia intercrops (K*sh* 76,900ha^{-1} or USD 905 ha^{-1}) at current exchange rates. It is concluded that farmers will have a high yield advantage when they intercrop maize with artemisia to yield optimally on artemisinin and ensure food security, using a spacing of T_6 artemisia 0.9m *X 0.9m* and Maize *0.9m X 0.75m* in sub-humid areas of western Kenya or regions with similar AEZ.

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Introduction

Intercropping includes agroforestry (AF) practices that promote biodiversity (CBD, 2008), in which food crops are cultivated on the same land management unit as woody shrubs. This may either be in some form of temporal sequence or spatial arrangement (Lundgren and Raintree, 1982). Artemisia (*Artemisia annua* L.*)* is an aromatic medicinal shrub (Singh and Lai, 2001; Hayat *et al.,* 2009), whose cultivation is recommended for production of artemisinin used with combination therapy (ACT) in treating Malaria (WHO, 2008); while maize (*Zea mays* L.) is cultivated as a staple food crop in Kenya. Medicinal and aromatic plants have greater economic value than other crops; and intercropping maize with artemisia may have significant environmental and economic benefits (Chuan-chao *et al.*, 2009). Intercropping where shrubs are grown alongside food crops is among farm practices that may have great potential in enhancing the adaptive capacity of agricultural systems in sub-humid regions; and this can in time provide agroecological resilience to extremes of changing climate (Serigne *et al.*, 2006). This is especially applicable as an adaptation measure in farming areas constrained by diminished land sizes and low marketable yields of suitable intercrops to generate farm incomes and enhance food security.

The great diversity of farming systems under which maize is grown may be unmatched by other cereal crops in the world, and carefully chosen intercrops can be grown in the same field as maize without significantly reducing yields of either intercrop. Maize is cultivated as an intercrop with many crop species and is widely used in alley systems with hedgerows of artemisia in China (Ellman, 2006). When maize is intercropped with high-value, commercial fodder leguminous shrubs like Silverleaf (*Desmodium uncinatum*)*,* striga weeds were suppressed by more than 40 times (Khan *et al.,* 2006) in western Kenya. Artemisia has been successfully grown as an intercrop with coffee seedlings in Tanzania to minimise shading on stumped coffee, add organic matter to soil and give a return in an otherwise barren year for the pruned coffee (Griffee and Diemer, 2006). Artemisia is also used as a natural pesticide in Nepalese home gardens which consist mainly of vegetables, fruits and fodder (Sunwar, 2003). Smallholder farmers could hence make considerable savings by lowering the cost of production in terms of foregone herbicide usage and/or labour man-hours used for weeding maize + artemisia fields manually.

Smallholder farmers in Kenya practice intercropping mainly to maximise utilisation of land and labour and achieve higher intercrop yields. However, with small farm sizes averaging 0.5 ha per farm-family and reduced fallow periods (Otsyula and Nderitu, 1998) many intercrops may hardly be sufficient to meet the farmers' subsistence needs as well as cash income for other basic requirements. Farmers in the region also lack adequate knowledge of alternative intercrops with maize for risk aversion and crop diversification to sustain livelihood. Furthermore, widespread application of intercropping practices in which spacing is irregular and choice of crop components not commercially demand driven, may significantly contribute to low land use efficiency that affect biodiversity in fallow systems.

The term "Fallow" as conventionally used refers interchangeably to the actual plant species or agricultural land lying idle, either abandoned or as a means 'to rest tired soils'; and also the duration of time in the intervening periods when land is idle (Sanchez, 1999). Enriched fallows are those species with tangible economic yield advantage. While cultivation of maize (Smale and Jayne, 2003), for both commercial and subsistence farming is well documented, artemisia production as an intercrop is a fairly new practice in Kenya. The alternatives to maize intercrops have not been adequately exploited in the region, whereas intercropping with artemisia has potential for adoption as an enriched fallow in agroforestry systems by famers on account of promising economic returns. The ensuing diversification of crop enterprises and fallow periods through intercropping provides a buffer against consequences of environmental degradation (FAO, 2005).

Generally, intercropped maize in western Kenya is grown under low external input application regimes limited by scarce resources (Okalebo *et al.,* 1999) that affect choice of suitable intercropping options. The unplanned planting patterns as practiced in western Kenya may have significant implications on harvestable yield or value-added products from intercrops. There is also an inherent tendency for farmers in the region to invest in lower value commodities like maize because of their intrinsic value of ensuring food security, despite the high variable costs of production (Jaetzold *et al.,* 2005). Given this scenario, there is a limit to wide application of fallow systems with no tangible benefits, without compromising on increased crop biodiversity for short term food security.

A major advantage of an intercropping system with shrub hedgerows over monocropping as envisaged in this study, is that the cropping and fallow concepts can be applied simultaneously on the same land unit with sequential planting and variation of spacing. Moreover, the potential of intercropping to control both ordinary weeds (Chabi-Olaye *et al.,* 2005) and parasitic weeds such as *Striga hermonthica* in food crops (Gallagher *et al*., 1999) has been aptly demonstrated, specifically in protecting biodiversity in fallows through less or no usage of herbicides. This may be particularly important in intercropping systems with limited capacity for external inputs application, to save on variable costs of production.

Intercropping designs commonly employ either of two methods referred to as *Replacement* or *Additive*, depending on desired plant stand density of the monocrop relative to the intercrop (Fukai and Trenbath, 1993). There are however two distinct parameters that should be considered in the evaluation of intercropping advantages (Willey, 1985): a biological objective to determine the increased biological efficiency of intercropping; and a practical objective to determine tangible advantages that are likely to be obtained by a farmer. These dynamics need a thorough understanding before compromising on an ideal system performance of intercrops for recommendation to the farmers, since a biologically efficient system may not necessarily be economically viable (Ghulam *et al.*,2003).

Intercropping is a space, time and labour input dependent form of multi-functional agriculture and hence estimating yield advantages from intercrops require a tradeoff between alternative parameters for evaluating component interactions, which ultimately lead to the most desirable spacing regime. For comparative assessment, these parameters include Replacement Value of Intercropping, RVI (Van der Meer, [1989); Cost-Benefit analysis, CBA (Jaetzold, *et al*., 2005); and Dominance Analysis, DA (Perrin, *et al.,* 1988). While evaluating system performance, the primary objective of intercropping in this study was to achieve crop diversity from optimum yield of the staple crop of maize and additional income from the second crop of artemisia, so that the combination giving the best yield of the second crop without significantly reducing yield of the main crop for food security is realised.

Materials and methods

The study was carried out at the Maseno Research Farm of Maseno University, Kenya. Maseno is in the subhumid upper midland agroecological zone three (FAO, 1978). The altitude of the area is 1500m a.s.l., and the site is very close to the equator receiving a mean annual precipitation of 1750 mm with a bimodal distribution. Day temperatures average 28.70C (Jaetzold *et al.,* 2005). The soils in the area are of variable depth, classified as Acrisols being well drained, deep reddish brown clay, fairly acidic with pH ranging between 4.4 and 5.5, (Mwai, 2001) and are deficient of P and N, with a moderate fixation of P (Okalebo *et al.,* 1999). The experiment was carried out between September 2009 and August 2010, relying on rainfall precipitation of two consecutive seasons interspersed with a fallow period of 45 days.

The plant spatial arrangements were in 'Additive Series' (Fukai and Trenbath. 1993) to result in constant maize and bean population but varying artemisia plant densities, designed to allow for optimal artemisia crown development and minimise shading effect or intense competition from either crop component, while allowing for a 1m width foot path between plots and replicates. Land preparation was done manually [EABL, 2005], with each plot measuring 6m x 4m, i.e. 24m^2. The experiment had nine treatments, laid out as a randomized complete block design (RCBD) in 3 replications, as follows (Chumba, 2012):

T_1= *Artemisia 1m X 1m ; Maize 0.90m X 0.75m ;*
T_2= *Artemisia 1m X 0.75m ; Maize 0.90m X 0.75m ;*
T_3= *Artemisia 1m X0.9m ; Maize 0.90m X 0.75m;*
T_4 = *Artemisia 0.75m X 0.75m ; Maize 0.9m X 0.75m ;*
T_5= *Artemisia 0.9m X 0.75m ; Maize 0.9m X 0.75m ;*
T_6 = *Artemisia 0.9m X 0.9m ; Maize 0.9m X 0.75m ;*
T_7= *Maize 0.90m X 0.75m (Pure Stand);*
T_8 = *Artemisia 1m X 1m (Pure Stand);*

The maize cultivar used was the hybrid H513 adapted to medium altitude agroecological zones and is an early maturing variety, while the artemisia seedlings used were F_1 vegetatively propagated and sourced from an East African Botanical Limited (EABL) contracted nursery. Unlike maize, artemisia did not need planting fertilizer to break even (Delabays *et al.,* 1993). Maize was planted with di-ammonium phosphate fertilizer (DAP) and thinned to one seed per stand, while artemisia was transplanted at approximately 30cm in height when maize was at knee-high length ready for 1st weeding. Maize was spaced constantly at 90 cm inter row and 75 cm intra row to result in a low density of 20,333 plant ha^{-1}.

Localised application of top dressing fertilizer, calcium ammonium nitrate (CAN) was applied to maize once at 6 weeks after planting (WAP). Weeding was done manually as need arose. Harvesting of artemisia was done when the plants started showing signs of bud initiation in accordance with Ferreira *et al.*, (2005). The harvesting of both intercrops was limited to manual techniques where whole crop of artemisia is severed at the root apex and sundried on black polythene sheets, threshed for leaves, packed in small bags and ready for delivery to laboratory for artemisinin analysis.

Above ground dry biomass was determined from severed shoots. The second and long rain season (LR) land preparation incorporated into the soil non-woody plant material from previous intercrops according to the practices of Okalebo *et al.,* (1999) and Ferreira *et al.*, (2005) for maize and artemisia respectively. The yield components and yield for all intercrops was averaged from 5 hills derived from a net plot of 24m^2 and extrapolated into production per hectare where applicable. Yield of maize grain at 12 % moisture content was measured using moisture meter and recorded at harvest for the two seasons.

Both seasons crop of artemisia was harvested whole, fresh and dry weight of leaves recorded and artemisinin content determined for each treatment after a storage period of 2months at room temperature to mimic farmer's practice. Artemisinin content was determined following the method of Christen and Veuthey (2001). This method entails grinding dry artemisia leaf at 8% moisture content to powder, followed by extraction and analysis of artemisinin content using HPLC with mass spectroscopy (MS).

Non-destructive measurement of chlorophyll content of the leaves was done using a SPAD-502 meter, three times each season within a weeks' interval for both season's crops prior to harvest according to the method of Peng *et al.*, (1992). Triplicate readings (SPAD Units) were taken around the midrib of each sample leaf, within 15cm of shoot apex and averaged per plant for all treatments. A correlation analysis between chlorophyll (x) and artemisinin (y) content of artemisia at harvest time was done manually using Pearson's Correlation Coefficient (r):-

$$r = \frac{n\sum xy - \left(\sum x\right)\left(\sum y\right)}{\sqrt{n\left(\sum x^2\right) - \left(\sum x\right)^2}\sqrt{n\left(\sum y^2\right) - \left(\sum y\right)^2}} \quad \textbf{(1)}$$

Replacement Value of Intercropping (RVI)

As a measure of relative economic yield advantage of intercropping artemisia and maize, RVI was determined for each crop per treatment to account for variable costs used in the production process of the intercropping systems, following the method of Van der Meer **(**1989); as modified by Moseley (1994) for agroforestry cultivation systems that incorporate a fallow period. Partial RVI for artemisia and maize were summed and averaged per treatment. Substituting for artemisia + maize interchangeably, the RVI was computed thus (Moseley, 1994):

$$RVI = \{[aY_1 + bY_2]\,[Gp/(Gp + Fp)]\} / \{[a\,MY_1 - C]\,[Gm/(Gm + Fm)]\} \quad (2)$$

Where:

Y_1 and **Y_2** are the yields of artemisia or maize in any 2-crop mixture respectively. **MY_1** is the mono crop yields of artemisia or maize each to be used interchangeably with the respective companion crop; **a** is the market prices of crop Y_1; **b** is the market price of crop Y_2 to be used interchangeably for all crops; **C** is the variable cost associated with mono-cropping artemisia or maize interchangeably intended for replacement i.e. labour costs, cost of planting material and fertilizer. ***Gp*** and ***Gm*** represent the number of growing years for polyculture and monoculture respectively; and ***Fp*** and ***Fm*** represent the number of fallow years for polyculture and rnonoculture respectively.

Equation (2) data above was subjected to analysis of variance (ANOVA) using the Costat Version 6.4 statistical computer package, while the treatment means were separated using the least significant differences (LSD) test at 0.05% level.

Cost-Benefit analysis (CBA)

Assuming that a biologically efficient system may or may not be also economically efficient; a cost-benefit analysis (Jaetzold, *et al.*, 2005) was used to develop a simple economic model for all treatments that would be easy to use or interpret by both farmers and extension. Data on labour requirements were collected and recorded each season for all field operations (land preparation, planting, fertilizer application, weeding and harvesting). Cost-benefit analysis (CBA) was done according to the prescription of Jaetzold and Schmidt, (1983) and Makeham and Malcolm, (1986), where land as a raw material in production was assumed to be a fixed input because it does not change in the short run and was therefore not costed; while the production or variable costs included labour and non-labour expenses. Prevailing market prices at the time of study for artemisia dry leaf (Ksh 40 per kg) and maize (Ksh 2500 per 90kg bag) was used for analysis of monetary benefits.

The costs and amount of hours spent on bush clearing, planting, weeding, fertilizer application and harvesting were recorded on per treatment basis and converted to man-days (MD) ha^{-1} using the equation of Alabi and Esobhawan, (2006) but using local rates of K*Sh* 200.00 (USD 2.35) per MD for labour costs**:-**

$$\mathbf{MD = H/T} \quad \textbf{(3)}$$

Where *H* is the cumulative hours of labour input and *T* is time of 8 hours.

All other costs were computed from each treatment on the basis of prevailing market price of fertiliser, artemisia leaf yield, and maize grains. The economic analysis was performed on cumulated costs and benefits over the 2 seasons SR and LR. All costs were extrapolated into Kenya shillings (Ksh) per Ha. for each treatment. The difference between total benefits and total variable costs was then recorded as net benefit per treatment (Table 3). By making simple comparisons of the ensuing amounts, this model determined what numerical advantages (in terms of economic profitability) are to be obtained from intercropping maize with artemisia or in respective monocultures.

Dominance analysis (DA)

Determination of Cost-Benefit analysis was followed thereafter by a dominance analysis according to the method of Perrin *et al.,* (1988). Because of the twin objectives of ensuring food security as well as income from the tested intercrops, T_8 (artemisia pure stand) was the bench mark for dominating treatments after recording higher CBA values than T_7 (maize pure stand). The dominance analysis (DA) entailed first arranging all variable costs' treatment in ascending order from highest to lowest. A treatment was considered dominated (D) hence inferior and discarded, if its variable costs were higher than the preceding treatment without a corresponding increase in net benefits (Perrin *et al.,* 1988). All "Undominated" treatments were then subsequently ranked by re-arranging them in ascending order from least to highest variable costs to indicate superior spacing regimes (Table 3). Thus, the most superior spacing regime from among the treatments is one which is Undominated with least variable cost implication.

Results and discussion

The data on Replacement Value of Intercropping (RVI) , artemisinin yields (%Art), cost-benefit analysis (CBA), and dominance analysis (DA) obtained from monocrops as well as the respective intercropping systems of maize + artemisia in different spacing regimes are presented in Tables 1, 2, 3 and 4 respectively. In general, artemisia flowered differentially in the two seasons and exhibited a potential for short season ratooning. This has potential to maximise leaf yield and reduce the cost of field preparation and production in cases of low availability of planting material. In addition, the artemisia component may have weed suppression ability in maize+artemisia intercrops that need more investigation: A critical observation was that after canopy closure of artemisia no weeds emerged after the first weeding operation. As a result, this necessitated that the number of weedings by manual uprooting be restricted to one for all artemisia intercrops, and two for maize monocrops in both SR and LR seasons with a consequent reduction of labour costs in artemisia stands by half and increase in variable costs of maize monocrops.

Artemisin Yields

The short rains (SR) treatments had a significant effect on artemisinin yields (P>0.05) but lower content of 0.74% on average than during the LR season mean of 0.8% (Table 1). Apart from T_8 (pure stand), T_4, T_3 and T_2 exhibited the highest % artemisinin than the other treatments at 0.81%, 0.78% and 0.74% respectively. There was also a positive correlation ($r^2=0.7$) between artemisinin and relative chlorophyll content at immediate pre-harvest period (Table 2).

Assuming presence of interplant competition with maize+artemisia system as compared to artemisia monocrops, T_1 may thus represent a spacing regime that is not desirable when targeting optimum yields of artemsinin from among the treatments. Furthermore, T_4, T_3, T_2 and T_6 were not statistically different from each other but also exhibited superior artemisinin % yield, implying that these intercropping spacing regimes are equally better than all the other treatments. In addition, this trial produced a mean artemisinin yield of 0.77% averaged from both the SR and LR seasons, which is above the world average of 0.6% as reported by Ferreira *et al.,* [2005]. Artemisin yields of 0.77% also translates to about 15.4kg ha^{-1} which is more than the global average of 6-14kg ha^{-1} (Kindermans *et al.*, 2007). The results are in general agreement with Heemskerk *et al.*, (2006) that given its proximity to the equator, Kenya has the potential of producing the crop with yields of the active ingredient higher than that obtained from the varieties cultivated in Asia. Since artemisinin is a secondary metabolite, climatic conditions, together with the time of planting and harvesting artemisia can influence artemisinin production (Marchese *et al.,* 2002). This may help to explain why spacing had an effect on artemisinin yields from the SR; while the artemisia crop grown in the short rains (SR) had less artemisinin content than the Long rains crop, to have a significant seasonal effect on RVI, on account of the weather variations experienced in the two seasons.

Table 1. Effect of Spacing Maize and Artemisia on % Artemisinin Content (AC), Chlorophyll content and Replacement Value of Intercropping (RVI).

$^{+}$**Treatment**	**Plant Pop (24m^2)**	**% Artemisin content**		**Mean Chlorophyll SPAD Units**		**RVI**	
		LR	SR	Artemisia	Maize	Artemisia	Maize
T1	85	0.76ab	0.65b	5.95a	35.5ab	1.3bc	1.6ab
T2	78	0.84a	0.74ab	6.67a	37.9ab	1.4bc	1.5b
T3	74	0.76ab	0.78a	5.98a	37.6ab	1.4bc	1.5b
T4	90	0.83a	0.81a	6.30a	37.7ab	1.5b	1.5b
T5	90	0.71ab	0.68ab	6.12a	37.5ab	1.5b	1.5b
T6	85	0.82a	0.68ab	6.10a	38.7ab	1.6a	1.7a
T7	50	-	-	-	39.1a	-	1.0d
T8	35	0.89a	0.86a	6.65a	-	1.0d	-
CV%	-	8.12	7.51	14.8	7.38	10.78	21.25
LSD0.05	-	0.13	0.12	1.1	4.3	0.09	0.16
Spacing	-	ns	*	ns	ns	*	*
Season	-	*	*	*	ns	ns	*

{Mean values in a column followed by dissimilar letter (s) indicate significant differences at 0.05 (*) level ;
ns=Not significant at P>0.05; SR=Short Rains; LR=Long Rains; CV= coefficient of variation}

$^{+}$LEGEND:
T1 = Artemisia 1m X 1m; Maize 0.90m X 0.75m; T2 = Artemisia 1m X 0.75m; Maize 0.90m X 0.75m
T3 = Artemisia 1m X0.9m; Maize 0.90m X 0.75m; T4 = Artemisia 0.75m X 0.75m; Maize 0.9m X 0.75m
T5 = Artemisia 0.9m X 0.75m ; Maize 0.9m X 0.75m ; T6 = Artemisia 0.9m X 0.9m ; Maize 0.9m X 0.75m
T7 = Maize 0.90m X 0.75m (Pure Stand) T8 = Artemisia 1m X 1m (Pure Stand)

Table 2. Effect of Spacing Artemisia and Maize on % Artemisinin (Art) and Chlorophyll Content (Chl).

$^{+}$**Treatment**	**Art.SR (Y)**	**Chl (X)**	**X*Y**	**X2**	**Y2**
T1	0.65b	5.95a	3.87	35.4	0.422
T2	0.74ab	6.67a	4.94	44.49	0.547
T3	0.78a	5.98a	4.66	35.76	0.608
T4	0.81a	6.30a	5.04	39.69	0.64
T5	0.68ab	6.12a	4.16	37.45	0.462
T6	0.68ab	6.10a	4.15	37.21	0.462
T8	0.86a	6.65a	5.72	44.22	0.74
CV %	7.51	14.8	-	-	-
Mean	0.741	6.25a	4.65	39.17	0.555
LSD 0.05	0.12	-	-	-	-
Significance	*	ns	-	-	-
∑ (T1-T8)	5.19	43.77	32.54	274.23	3.883
∑	∑Y =0 .54	∑X =5.01	∑XY =3.90	∑X2=36.11	∑Y2=0.42
r^2	0.7				

Table 3. Cost benefit analysis (CBA) in *Ksh ‘000 ha^{-1}.

Treatment^{+}	**T_1**	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**	**T_7**	**T_8**
Benefits'000/ha *								
Maize	7.36	6.6	6.16	6.16	6.16	6.28	8.76	-
Artemisia	65.8	80.8	98.6	97.0	100.0	96.80	-	107.6
Total Benefit	73.2	87.4	104.8	103.2	106.2	103.1	8.76	107.6
Variable Costs'000/ha *								
Labour	7.80	7.80	7.80	7.80	7.80	7.80	4.2	3.6
Maize seed	4.15	4.15	4.15	4.15	4.15	4.15	4.15	-
Artemisia seed	3.85	3.08	2.64	4.40	4.40	3.85	-	3.85
Fertiliser	7.70	7.70	7.70	7.70	7.70	7.70	7.70	0
Total Variable cost	23.50	22.73	22.29	24.05	24.05	23.50	16.05	7.45
***Net Benefit* *Ksh’000/ha**	49.70	64.70	82.50	79.20	82.20	79.60	(7.3)	100.20

{ *1USD=K*sh* 85 }

$^{+}$LEGEND:

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

Table 4. Dominance Analysis (D) of Maize+Artemisia intercrops.

Spacing*	**Art Plant Density ha^{-1}**	**VC '000 K*sh* ha^{-1}**	**Net B '000 K*sh* ha^{-1}**	**Dominance**
T_1	14,583	23.5	49.7	D*
T_2	11,667	22.7	64.7	D*
T_3	10,000	22.3	82.5	-
T_4	16,667	24.1	79.2	D*
T_5	16,667	24.1	82.2	-
T_6	14,583	23.5	80.3	-
T_7	-	16.05	-7.3	D*
T_8	14,583	8.1	99.6	-

{VC: costs that Vary; D* Inferior Spacing regimes (Dominated); NetB: Net Benefits; K*sh* –Kenya Shillings}

*LEGEND:-

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

Despite recording a RVI of unit value hence no advantage to intercropping, T_8 artemisia pure stand obtained the highest % artemsinin yields (Table 1). Assuming absence of intense competition with maize+artemisia system compared to artemisia pure stand on account of these plants’ growth and morphological characteristics, there may have been more efficient resource capture to facilitate growth and a biological yield advantage of the latter system. This may further suggest that intercropping maize with artemisia under the tested treatments had a net effect of reducing artemisinin yields, probably resulting from negative component interactions or interspecies competition between maize and artemisia. A similar and disadvantageous biological yield to intercropping has been reported between okra (*Abelmoschus esculentus* L. *Moench*) and vegetable amaranth (*Amaranthus hybridus* L.) by Muoneke and Ndukwe (2008), where okra depressed the growth and yield of amaranthus at higher plant densities of the latter.

The Leaf chlorophyll content may be a function of both soil and leaf N at any point in time during active vegetetative growth of agroforestry components. However, the different spacing regimes did not affect the Chlorophyll content of either intercrop, suggesting that all the tested planting patterns did not constitute crowded conditions to result in significant competition for radiation and soil nutrients especially N. This suggests compatibility in resource capture between the two component crops of maize and artemisia. In addition, the positive correlation between chlorophyll and artemisinin sequestration, suggests that it is possible to manipulate N application and radiation levels to improve artemisia leaf extracts. Similar results have been obtained from Lettuce (*Lactuca sativa* L.) by Mitchell *et al.*, (1991) and artemisia by Banyai *et al.*, (2010), the latter through exogenous GA_3 treatment.

Replacement Value of Intercropping (RVI)

The replacement value of agroforestry is the factor by which the polyculture is more or less valuable than the monoculture (Moseley, 1994); and since the fallow period employed in this study was less than unit value (i.e. 1 year), it follows from equation (1) above that $Gp=1$, $Fp=1$, $Fm = 0$, hence $Gm/(Gm + Fm) = 1$; and consequently, the RVI index reflects the extent to which the artemisia+maize intercrop is more or less valuable than their respective monocrop in an annual growth cycle. Spacing had a significant effect ($P>0.05$) on RVI values (Table 1). The highest recorded RVI for artemisia and maize was from T_6, and this suggests that intercropping maize with artemisia will yield an optimum biological yield advantage of between 60% and 70% more than respective monocultures.

The higher the RVI value, the better the polyculture combination relative to respective monocrop for a yield advantage. Higher RVI of artemisia compared to maize suggest that replacing maize with artemisia will not add value to maize monoculture. Assuming absence of intense intra-plant competition in this study on account of relative uniformity in yield patterns from the treatments, the shortened 45-day fallow period may have been the determining factor in yield advantage of the intercrops in spatial terms. The increased profit (or gain) obtained from all intercrops may also have been occasioned by shortening of the fallow period to cultivate twice in a year, as was postulated by Moseley, (1994) when analyzing whether increased intercrop yields are due from shortened fallow periods, interplant complementarity or increased competition in an annual growth cycle as compared to perennial cultivation. Since seasonal variation did not have a significant effect on RVI, another implication of high values may indicate efficient use of available time in the growing season since both crops can be grown twice annually with a shortened fallow period. Lower variable costs for artemisia than maize suggest that when similar intercropping treatments are used for the production of low-value crops such as maize in Kenya, the higher maize yield from these technologies may not be sufficient to compensate for the higher total variable costs particularly of labour and commercial fertilizers for the maize. This may be due to the consequent reduction or replacement in variable costs of labour and fertilizer that are associated with artemisia+maize intercrops relative to maize monocrops.

In this study, the increased benefit accruing to the farmer is through manipulation of labour attributes like the weeding regimes that are reduced by half as a result of single application to cover two crops, and reduction in cost of fertilizer by single application in inter-cropping compared to monocropping. The man-days used in weeding of intercrops may have been reduced considerably as a result of inherent ability of the companion crop of artemisia to suppress the weeds. A similar observation was made by Kumar *et al.*, (1987), while studying the production of maize and associated intercrops in relation to spatial arrangements. As labour becomes scarce with respect to available land, intercropping may become more attractive due to the savings in cash inputs; and AF shrubs (as cash crop) increase in value relative to food crops cultivated by small scale farmers.

Cost-Benefit Analysis (CBA)

All treatments subjected to cost-benefit analysis (Table 3) in 000' Kenya Shillings (K*sh*) ha^{-1} yielded maximum values from T_3 at 82.5, (USD 970.5) followed by T_5 at 82.2 (USD 967) and T_6 at 80.3(USD 944.7); The pure stands of T_7 (maize) and T_8 (artemisia) recorded very low and high CBA values of -7.3(USD 78.8) and 100.2 (USD 970.5) respectively. The mean economic value of the artemisia pure stand (K*sh* 100,200 or USD 1179) was highest. All the intercrops returned a biological yield advantage over the maize monocrop when using RVI values as an indicator of system productivity and hence by using CBA, the potential agroeconomic benefits or loss of the intercropping system may more accurately be used to target food security and higher income for the small scale farmer. The price offered to maize farmers per 90kg bag during the duration of this study fluctuated greatly between Kenya Shilling K*Sh* 1800 (USD 21.2) in January and K*sh* 4600 (USD 54.1) in June, to average at K*Sh* 2500 (USD 29.4). The commercial buyer (EABL) offered K*sh* 40 kg^{-1} (USD 0.47) for all dried artemisia leaf with a threshold value of 0.6% artemisinin content, irrespective of higher content. All artemisia treatments exceeded the threshold for artemisinin (Table1) acceptable for marketing purposes, suggesting that maize+artemisia treatments represents superior spacing regimes on basis of economic yield potential

Net benefits from the additive intercrop T_3 were higher than that from other intercrops (Table 3). On basis of grain yield for maize and artemisinin content for artemisia, there could be significant variation between economic yield and biological yield of the artemisia+maize intercrop on account of the aforesaid artemisinin pricing regime, and fluctuating low market price for maize. T_3 recorded the highest CBA value apart from the control of T_8, while T_7 (sole maize) had the lowest CBA value. Thus, the difference between CBA values of T_7 and T_3 at K*sh* 89,800 ha^{-1} (USD 1056) may effectively constitute in monetary terms, the optimal yield advantage of artemisia+maize intercropping system over maize sole crops in this study. Banik *et al.,* (2006) also recommended wheat (*Triticum aestivum*) + chickpea (*Cicer arietinum*) additive intercrops for their higher net income besides more efficient utilization of resources and weed suppression. In addition, the high CBA value resulting from T_3 may be more to do with cost saving than better harvestable yields. This is because the artemisia plant density in T_3 was lower (Table 1) hence lower costs of planting material and by extension, lower variable costs.

Since T_3 (maize+artemisia) and T_8 (artemisia pure stand) recorded the highest CBA values than other treatments, suggests that biological yield advantage (T_6) does not always imply an economic yield advantage (T_3) for artemisia+maize intercrops: Biological yield advantage from RVI values as in T_6 did not translate into an economical yield advantage, while artemisia pure stand T_8 was biologically less beneficial but economically superior using CBA. This may thus suggest that complimentarity of resource use occurred in the former system where one of the component species of the intercrop may have exerted a positive effect on the other, as was reported by Fukai and Trenbath, (1993). The high CBA value obtained from T_3 may thus be more as result of cost saving than better marketable yields on account of lower plant densities (Table 1) hence reduced costs of planting material. While working on maize+okra intercrops, Alabi and Esobhawan (2005) also reported that any strategy that reduces cost of production in intercrops will increase its profitability and attractiveness to farmers.

Dominance Analysis (DA)

The potential benefits or loss of any intercropping system can be due to increased yields, decreased input costs or a combination of both, hence the basis of a dominance analysis (Perrin, *et al.,* 1988) in this study for isolating optimal spacing regimes with a capacity of ensuring food security as well as to generate income from the intercrops. A spacing regime in this study was considered superior on basis of DA, if it was undominated and with the least variable costs (Table 4).

The “Undominated” treatment (Perrin, *et al.,* 1988) with the highest net benefit from CBA becomes the tentative recommendation to farmers, according to Boughton *et al*., (1990). Yield advantage is important if it translates into economic gains and presumably higher land use efficiency for the farmer. Since use of fertilizer at the recommended rates in this study produced higher variable costs, this may suggest the need to adopt intercropping systems that can yield optimally without depending on extra input application in order to sustain food security for smallholders.

The intercropping systems which were dominated in a dominance analysis were discarded as inferior from the available options and listed as ‘D’ (Table 4). The “Undominated” treatments (Perrin, *et al.,* 1988) were ranked from the highest best pure stand T_8 to the lowest variable cost treatment T_6. The dominated intercropping systems were infact less profitable than the rest. In contrast to maize+beans (T_9), maize+artemisia T_3 was the system with the highest net benefit ha^{-1} of arable land but not statistically different from T_5 and T_6 when biological yield advantage is considered. Since the superiority of T_3 may have been due to reduced variable costs from lower planting density than high harvestable yields, this suggests that T_3, T_5, T_6 and T_9 are all suitable for recommendation, subject to choice of crop components and desired level of intensification by the farmer. This corroborates with Boughton *et al*., (1990) that although dominance and CBA show the superiority of some of the intercropping systems over the others, the farmers’ choice will still depend on sensitivity in returns and risk attitudes, as well as prevailing market rates. Thus, the implication for maize+beans system is that when similar intercropping treatments are used for the production of low-value crops such as maize, the higher maize yield from these systems may not be sufficient to compensate for the higher total variable costs particularly of labour for beans, and commercial fertilizers for the maize. A similar observation was made by Odhiambo and Ariga (2001) while working on maize+beans intercrop to control striga weeds in western Kenya, and found that farmers failed to raise gross income despite heavy input, as a result of the low market price for maize.

One unusual result was the high agroeconomic value of artemisia monocrop over all intercrops (Table 3); since successful intercropping systems should provide a total yield value greater than if the crops are growing solo. This may be attributable to the high pricing regime of the artemisinin end-product as well as a comparative reduction in variable costs associated with fertilizer and weeding in the artemisia monocrop. The study demonstrated lower variable costs for artemisia than maize (Table 3) because of the avoided labour in weeding and non-use of soil applied commercial fertilizer on artemisia; suggesting that the non-use of fertilizer and presumed weed suppression ability of artemisia component resulted in no requirement for attendant costs that vary. These also suggest that the artemisia component in the intercrops may have benefited from synergistic effect of fertilizing maize to yield optimally.

Labour and opportunity costs did not differ between intercropping systems or seasons. However, non-labour costs were higher in all intercrops than monocrops, because of the varying price of planting material as a result of different plant density in the treatments. Land use efficiency was thus compromised for attaining food security with maize, because biological yield advantage was not commensurate with economical yield benefit. Similar conclusions were derived by Wannawong *et al.*,(1991) who used cost-benefit analysis while studying leucaena (*Leucaena leucocephala*) and acacia (*Acacia auriculiformis*) inter-cropped with cassava (*Manihot esculenta*) or mungbean (*Vigna radiata*) over 3-year rotations; and demonstrated that early supplementary and complementary relationships between some system components can imply synergistic financial gains but the biological interactions turn competitive over time.

Since biological yield advantage as postulated in this study may not translate to economic yield advantage for maize, the use of CBA as a tool for evaluating economic yield advantage of intercropping systems with some shrubs and food crops in the longer term may present a challenge when compromising between food security and economic yield advantage from such intercropping systems as artemisia+maize in regions with comparable pricing regimes and agroecological profiles to western Kenya.

Conclusion

As a trade-off, all the analysis techniques isolated T_3, and T_6, as potentially profitable spacing regimes depending on level of intensification desired by the farmer. While intercropping maize with artemisia, the basis of quantifying a yield advantage in either of these techniques is complementarity in the use of growth resources for artemisinin yields and food security from maize. In so doing, the most suitable spacing regime is T_6 (Artemisia 0.9m X 0.9m; Maize 0.9m X 0.75m) that exhibited a cumulative net positive effect of the tested biological and economic yield attributes.

The mean artemisinin content from artemisia in western Kenya is 0.8% and for significantly higher artemisinin yields of 0.9% or more, artemisia pure stands are preferable to artemisia+maize intercrops in agroecological zones similar to western Kenya. For efficient land use practices on relatively small farm sizes; and if small to medium scale farmers in the region can embrace farming as a business with institutional support that guarantees consistent demand for artemisinin as the curative agent for disease control, growing of artemisia intercropped with maize will create higher farm incomes averaging between Ksh79, 200 to Ksh 82,500 ha^{-1}. As fallow land for agriculture development diminishes, the benefits accruing from medicinal and aromatic plant species can best be enhanced by integrating artemisia shrubs into maize production systems to sustainably provide livelihood and manage the biodiversity of productive landscapes.

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