Effect of Spacing on Yield of Maize (*Zea mays* L) and Artemisia (*Artemisia annua* L) intercrops in a Sub-humid tropical ecozone of Maseno - Kenya

By

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ABSTRACT

Artemisia (*Artemisia annua* L.) is a medicinal shrub whose extracts include artemisinin as the active ingredient that treats malaria in combination therapy, while maize (*Zea mays* L.) is a staple food crop in Kenya. An agroforestry (AF) production system that entails intercropping maize and artemisia with optimal component interactions could provide an alternative and viable land use option. This study investigated the yield patterns of selected artemisia + maize intercropping spacings for optimum yield of maize and quality of artemisinin; with respect to land use potential in a sub-humid tropical climate. The experiment was carried out in two consecutive rain seasons interspersed with a short fallow period of 45 days from 2009 to 2010. There were 9 treatments, laid out in a RCBD design with 3 replications. Each replication had three different artemisia intrahedge spacing of 0.75m, 0.90m and 1m from each hedge, and uniform displacements of 0.75m X 0.90m for maize. A control plot of maize+beans intercrop was used for comparative analysis of yield advantages using Land Equivalent Ratios (LER), with respect to artemisia+maize yield. The Replacement Value of Intercropping (RVI), Competitive Ratio (CR), Area-Time Equivalent Ratio (ATER), Cost-Benefit Analysis (CBA) and (Land Use Efficiency) LUE were the parameters used to evaluate yield potential of the artemisia+maize intercrops. Ensuing data were subjected to ANOVA using the Costat statistical package while means separation was done with Bartlett's LSD at 5% significance Level. Pearson's coefficient was used for correlation analysis of artemisinin yield and chlorophyll content of artemisia. There was no significant effect of the spacings tested on major morphological characteristics of either intercrop ($P>0.05$); but spacing had a significant effect on yield of maize and quality of artemisinin produced ($P<0.05$). The treatments had a significant effect ($P<0.05$) on LUE, CR, ATER and LER for both maize and artemisia. Unlike artemisia RVI ($P>0.05$), the treatments did not have a significant effect on maize RVI ($P>0.05$). The LER indices proved an overestimation of yield potential compared to ATER while maize+artemisia intercrops had a 34% more biological yield advantage than maize+beans system under the same management system. The artemisia treatments had a significant effect on artemisinin yield ($P<0.05$), by exhibiting a high mean of 0.8%. There was also a strong positive correlation between chlorophyll and artemisinin accumulation ($r^2 = 0.7$), and when optimum artemisinin yields are desired, a spacing of T_4 (*Artemisia 0.75m X 0.75m; Maize 0.9m X 0.75m*) is recommended after producing the highest artemisinin level of 0.82%. When maize is the crop of choice for food security on basis of desired high grain yields, a spacing regime of T_1 (*Artemisia 1m* X *1m; Maize 0.90m* X *0.75m*) was superior and is thus recommended for the purpose. In general however, T_3 (*Artemisia 1m X 0.9m; Maize 0.90m X 0.75m*) and T_6 (*Artemisia 0.90m* X *0.9m; Maize 0.90m* X *0.75m*) were most suitable on basis of economic and biological yield advantages respectively, to generate farm incomes of upto K*sh* 82,500ha^{-1} (USD 971 ha^{-1}) and sustain food security from AF practices in Kenya or regions with similar agro-ecological zones to Maseno.

CHAPTER ONE: INTRODUCTION

1.1 Background

Agroforestry (AF) as a discipline first caught the attention of the scientific community in the mid-seventies [Nair, 1993]. As an AF practice, Intercropping has now become a feasible land use option of choice, due to its potential in enhancing the objectives of some key global conventions for sustainable livelihoods, i.e. Food Security vis-a-vis Climate Change adaptation [FAO, 2007] and Biological Diversity [CBD, 1993]. Agricultural development, environmental protection, and human well-being all depend on healthy ecosystems but according to the Alternatives to Slash and Burn (ASB) consortium [2008], biodiversity as a determinant of healthy ecosystems for sustainable livelihoods is being lost at historically high rates, with potentially catastrophic consequences. The FAO [2009] further estimates that 1.02 billion people in developing countries cannot sustain healthy active lives; while diseases' pandemics like malaria are negatively affecting households socially and economically [WHO, 2008]. Intercropping maize (*Zea mays* L.) as a staple food crop with medicinal shrubs like artemisia (*Artemisia annua* L.) may thus present an alternative and viable land use option to not only enhance biodiversity conservation but also sustain livelihoods.

With maize monocropping or intercropping with legumes continuously as is the norm in farm practice, many of the farmers in western Kenya lack adequate knowledge of alternative intercrops for diversification to raise an income and sustain livelihood. The farmers consistently engage in poor land management practices [Jaetzold *et al.*, 2005], thus eroding the natural resource base and capacity for enhancing food security. Successful AF intercropping systems should provide a total yield value greater than if the crops are growing separately, but unsuitable cropping protocols continue being both a cause and consequence of poor land use practices particularly in densely populated and sloppy agricultural landscapes. This is compounded by poor planning in which spacing is irregular [Macharia and Shiluli, 2003] and choice of crop components not commercially demand driven. This scenario impacts negatively on survival of bio-diversity, food security and general livelihood in Agro-Ecological Zones (AEZ) of western Kenya, where a large portion of the population is dependent on maize as the staple food crop.

There are also some major global challenges at play including the climate change phenomenon, which may lead to small scale farmers' apathy to livelihood from maize monocropping or intercropping with legumes like the common beans (*Phaseolus vulgaris*). Maseno area of western Kenya experiences a bimodal rainfall pattern with two peaks, which also represent the two main rainfed planting seasons in the region interspersed with a fallow period. However, fluctuations in both seasons: the long rains- LR (730 mm) and the short rains - SR (376mm) are becoming more common in recent years with a likelihood of crop failure in one out of five years [Birech *et al.,* 2008]. Considering that increased demographic pressure has diminished traditional fallow periods [Otsyula and Nderitu, 1998], smallholder farms in the sub-humid tropics dependent on subsistence agriculture could thus imply a more vulnerable situation to erratic rainfall as a consequence of climate change. Thus, emphasis on cropping systems dependent on maize cultivation or intercropped with beans might not be the best option to sustain agricultural production in the long term from densely populated AEZs, as compared to intercropping with shortened fallow periods and fewer risks of crop failure [swift and Ingram, 1996]. In situations of unpredictable rainfall patterns AF intercropping systems may thus have great potential to provide opportunities for climate change adaptation. Maize has successfully been cultivated under various fallow systems in Kenya [Amadalo *et al.*, 2003]; while artemisia as a medicinal shrub is a suitable candidate for enriched fallow systems, alongside the other fallow species that have economic yield advantage for facilitating honey or fuel wood production [Sanchez, 1999] and medicine.

In Maseno area where AF is almost synonymous with intercropping maize with "fertilizer trees/shrubs" for improved fallow systems, AF has been shown to reduce the distance traveled to fetch woodfuel by half, and increased maize+beans intercrop production by over 50% [Ombai, 2009]. The role of fallow periods in nutrient recycling is also well documented in the region [Cadisch *et al.*, 2002; Ståhl *et al.*, 2005], and it may be worth to presume that there could be a certain threshold duration of time within which crop residues from a previous harvest is still beneficial to a subsequent intercrop stand. This should be manifested in Area-time Equivalent Ratio (ATER) values [Hiebsch and McCollum, 1987] of a second and subsequent cropping seasons, since yield variations in intercropping systems may be attributable to differential use of growth resources by the component crops. This may thus imply that promoting maize+artemisia AF intercropping systems with shortened fallow periods that presumably have fewer risks of total crop failure is a viable land use option.

However, many studies on AF practices from western Kenya in the past may have put skewed emphasis on fertilizer trees/shrubs whose potential economic benefits may not be readily apparent to the small scale maize farmer. While this does not demean the importance of fertilizer shrubs as a means of sustaining production through soil fertility improvement, market-based approaches for value addition to AF are widely viewed as having the potential to defray conservation costs and meet socio-economic objectives [Scherr, 1995]. Louise and Tauer [1992] further suggest that farmers who grow a non-food cash crop have more cropping options than those who do not and landholding size also influences diversity hence fallow periods, which rises to a maximum and then falls as the area cultivated per capita increases.

Commercial processing and marketing of shrub products and services may thus provide a new frontier for AF paradigm shifts to institutionalise small holder farming as a business, in order to achieve the millennium development goals (MDG): This is to the extent of developing such mechanisms as rewarding the rural poor for enhancing biodiversity through carbon credits [Garrity, 2004]. After value addition to shrub-food intercrop products, it is logical to expect higher and sustainable incomes for the farmer. Agroforestry products could hence be advocated by conservationists and development agencies for sustainable rural development in Kenya as potential alternative strategies to livelihood.

However, the numerous usage of maize after value addition other than as a staple food crop has not been exploited in western Kenya: The maize scutellum or cotyledon in botanical terms, is high in oil (35- 40%) and contains many substances which are active and important from the early stages of plant germination to growth and processing or consumption [Paliwal, 2000]. According to Krogars [2003], the most promising ingredient of maize is the starch Amylose, in producing biodegradable plastics to replace the use of polystyrene in packaging of agricultural products; and since starch is highly cost-effective, amylose-rich starch makes strong films with low oxygen permeability, hence can be effectively applied in industrial pharmaceutical production of film coated medicinal tablets, including anti-malaria drugs.

On the hand, artemisia shrubs are known to produce the active ingredient artemisinin, in use since 340 AD to cure chills and fevers in traditional Chinese medicine [Ferreira and Janick, 2009]; has great potential in treatment of breast cancer [Singh and Lai, 2001] and as contraceptives for women applied externally [Grandolini *et al.*, 1988]. Apart from the medicinal properties of artemisia, other uses of the crop with great local potential for exploitation include wood fuel, basketry, paper and control of grain storage pests [Tripathi *et* *al*., 2000]. Artemisia medicinal properties after value addition to yield the active ingredient of artemisinin is of great interest in this study because of its potential to upscale maize intercrops: Even without the necessity of extracting artemisinin, herbal combination therapy (HCT) using artemisia at farm level (or intercropped with suitable food crops) has shown capacity to contain opportunistic diseases by periodic consumption of artemisia Tea [Wilcox *et al.,* 2007]. Since artemisia is not native to Africa, the indigenous technical knowledge on traditional medicine in western Kenya could better be harnessed by understanding and catalyzing technological innovation [Douthwaite, 2002] through incorporating and patenting artemisia in herbal concoctions.

Pandey [2007] reports that AF intercropping systems can contribute variously to ecological, social and economic functions; and in order to promote the well-being of society, management of multifunctional Agroforestry needs strengthening by crafting market regimes for the products derived from AF. In contrast, a majority of the farming systems in Kenya is subsistence maize oriented despite low market value for maize [Nyoro, 2002] and hence the need to promote AF intercropping practices and potential based on priorities of farmers as guided by prevailing global market trends and biophysical considerations. This could start by determining the viability of certain intercropping systems targeting specific market niches, in comparison to existing practices before recommending to farmers and other stakeholders. In particular, the biological and economic yield advantage of selected artemisia+maize intercropping patterns as an AF practice within a shortened fallow period, with respect to productivity and efficiency of land use potential in a sub-humid AEZ has not been documented before.

The land Equivalent Ratio (LER) by Willey [1979] is conventionally used to evaluate potential yields from intercropping systems. However, estimating potential yield advantage using only LER as a stand-alone parameter from intercropping systems, on basis of food security in enhancing biodiversity and livelihoods could be a big challenge, and may not also present a more accurate evaluation. The combined use of several indices for component interactions and some derived parameters from LER may thus provide a basis for better evaluating the effect of intercropping maize with suitable cash/medicinal shrubs like artemisia. Such parameters include Competitive ratio, CR [Willey and Rao, 1980], Replacement Value of Agroforestry [Moseley, 1994], Cost-benefit analyses [Jaetzold and Schmidt, 1983] and Land Use Efficiency [Rao, 2002].

According to Willey [1985] there are both biological and practical objectives of intercropping to determine tangible advantages that are likely to be obtained by a farmer. Since a biologically efficient system may not necessarily be economically viable [Ghulam *et al.*,2003], more focus could be on measures to improve the resource base of the small scale farmer than on aspects of generating more technologies [Kipsat *et al.*, 2002]. In a multifunctional agriculture where farming is to be considered as a business for sustaining livelihoods, an AF production system that entails intercropping suitable food crops and medicinal shrubs with optimal component interactions could hence provide an alternative source of income and food security intervention in western Kenya. Within the context of this study therefore, AF is a basic integrated land management system with a potential socio-economic impact which optimizes above ground benefits arising from the biotic interactions created when a staple food crop like maize is intercropped with a promising medicinal shrub like artemisia in single hedgerows.

1.2 Statement of the Problem

The farming systems in sub-humid region around Maseno are characterised by very small farm sizes averaging 0.6 ha per farm family and a high population density of 880 - 1,100 persons per km^2 [KNBS, 2005]. Given this scenario, there is a limit to wide application of improved fallow systems, without compromising on land carrying capacity for income generation, short term food security or other tangible benefits. The potential of some intercropping systems for sustained crop production in the region has widely been demonstrated, but the challenge of persistently low agricultural productivity has resulted in a vicious cycle of low farm incomes and food insecurity. Farmers traditionally cultivate maize as a staple food crop using low inputs if any, with a regular intercrop of 'fertilizer trees' or legumes that are hardly sufficient to meet their subsistence needs or cash income to meet other basic requirements. In addition, most smallholder AF intercropping systems are characterized by limited proactive management and planning, where spacing is irregular and choice of crop components often the result of chance [Michon, 2005]. A majority of the farmers may also not be fully aware of the potential of AF intercropping systems in enhancing their capacity to adapt and increase on-farm biodiversity by manipulating fallow periods. Farming is rarely considered as a business by small scale farmers around Maseno. This is compounded by the fact that many such farmers often invest considerable time and effort because of the priorities of external agencies but not theirs [Chambers *et al.*, 2005]. They have tended to receive mixed signals over time regarding the most viable alternative to maize+legume intercrops as a food security intervention. Recommendations have been prescribed to the farmers often using inappropriate criteria and delivered on a take it or leave it basis [Collinson, 1989]. These farmers have not been exposed to AF intercropping technologies with tangible economic benefits from enriched fallows like in artemisia shrubs that also have medicinal value as an intercrop with the subsistence maize.

1.3 Objectives

1.3.1 Main Objective

To investigate the biological and economic yield advantage of selected artemisia + maize intercropping patterns as an agroforestry (AF) practice within a shortened fallow period, with respect to productivity and efficiency of land use potential in a sub-humid agroecological zone.

1.3.2 Specific Objectives

a) To determine the effect of intercropping artemisia and maize on biological and economical yield of maize and artemisia.

b) To compare the effect of intercropping artemisia+maize using different spacing regimes on quality of artemisinin.

c) To determine the yield advantage of artemisia+maize over maize+beans intercropping systems using Land Equivalent Ratios (LER) and Cost-Benefit Analysis (CBA).

1.3.3 Hypotheses

a) Artemisia+maize Intercrops will not yield significantly higher per unit area of land as compared to pure stands of each component.

b) Different spacings of artemisia+maize intercrops will result in insignificant differences in Quality of Artemisinin.

c) There is a higher yield advantage in maize+beans than artemisia+maize intercropping Systems.

1.4 Justification

Intercropping as an Agroforestry (AF) practice offers many practical possibilities for sustainable livelihood and is increasingly being promoted to enhance biodiversity and income generation for food security, but its effective role in adding value to the subsistence farming of western Kenya has not been adequately exploited. Since maize is the staple food crop in the region with a traditional element of Legume intercrops, the average land holding of 0.6 ha is far below the FAO recommendation for subsistence food purposes of 1.4 ha/ household [FAO, 1999]. This is despite the fact that AF intercropping in all its diverse applications enhances the efficiency of land use systems to impact positively on food security in AEZ with high density populations. Given the high population density in western Kenya, small farm sizes averaging an acre or less may preclude wide adoption of shrubs or farm trees with no tangible economic benefits, much as these technologies improve soil fertility or conserve biodiversity at the expense of the little available land intended for short term food security. For sustaining livelihoods, the ASB Consortium [2008] points out that AF intercropping systems when properly designed and not applied as a 'quick fix solution', can restore many of the watershed functions normally accredited to natural forests, and ensure increased diversity for long term food security.

Intercropping is a common feature in the agricultural landscapes of western Kenya as a traditional African practice, and provides farmers the opportunity to enhance biodiversity conservation on their farms in addition to managing risks of total crop failure. AF intercropping enhances biodiversity management at farm level and may thus have great potential to increase resilience to extremes of climate change for adaptation. Intercropping thus can ultimately present farmers with various crop and land management options from which they may choose the practices that best suit their site-specific needs and socio-economic conditions [Woomer, 2004]. The practice is also associated with low external input agriculture; and adopting low external input strategies as in AF intercropping or optimizing its practice could create several positive reinforcing feedback effects on small-scale Kenyan agriculture [Yengoh and Svensson, 2008].

The agronomic yield performance of AF systems may also be enhanced by managing more efficiently the interactions among components that determine intercrop productivity. Artemisia shrubs for example can profitably be cultivated without the necessity of fertilizer application and relatively few inputs are needed, because the plants do not seem to have any significant soil nutrient requirement, insect or disease infestation [Dalrymple, 2008]. Interest in the commercial production of artemisia has recently increased, since the shrub produces artemisinin as the active ingredient which when used in combination therapy (ACT) as recommended by the WHO [2008], treats malaria and greatly reduces the potential for resistance against the parasite *Plasmodium falciparum*.

Medicinal and Aromatic plants (MAPs) possess greater economic value than other crops, and hence intercropping maize with selected MAPs as an agroforestry strategy [Rao, 2004] may have significant environmental and economic benefits [Chuan-chao et *al*., 2009]. Furthermore, proximity of farmers to a recently constructed Kisumu international airport, offers immense potential to the farmers to diversify their sources of income, if viable and exportable medicinal shrubs like artemisia can be exploited to complement small scale maize production for income generation; as well as contribute towards the enhancement of human health after value addition to respective components. With optimal artemisia production from small scale farming, food security and biodiversity could thus be enhanced when the livelihoods of farming communities dependent on maize intercrops are guaranteed.

CHAPTER TWO: LITERATURE REVIEW

2.1 Intercropping in Agroforestry

Intercropping as an Agroforestry (AF) practice include systems in which agricultural crops are cultivated on the same land management unit as woody shrubs, either in some form of temporal sequence or spatial arrangement [Huxley and Van Houten, 1997; FAO, 2005]. Generally, AF systems in the sub-humid tropics are part of a continuum of landscapes for interrorw crops or grasslands for intensive homegardens [Abebe, 2005], grazing or agroforests in which the shrub/tree component can stay in the field for a prolonged period. With more than 38% of the global crop area severely degraded, there is a need to expand the use of Agroforestry practices in support of intercropping or multi-functional agriculture [Leakey, 2010], where more attention is being given to achieving stability in land utilization while fulfilling the subsistence needs of local populations [Swift and Ingram, 1996]. Intercropping where shrubs are grown alongside food crops is also among the AF technologies' reported to have great potential in enhancing the adaptive capacity of agricultural systems in sub-humid regions [Serigne *et al.*, 2006; FAO. 2009], which may in time provide agro-ecological resilience to extremes of changing environment. This could be especially applicable in areas where farmers are constrained by diminished land sizes and the use of commercial fertilizers to enhance food crop production [Okalebo *et al.,* 1999] in reference to maize. The practice of intercropping is economical, viable and apt in agroforestry systems [Sikolia *et al.,* 2009].

According to Reyes [2008], maize was traditionally intercropped in Africa through a cyclic rotation of planting the crops with indigenous and/or domesticated crops for a few years before the land was left to fallow. 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]. In Maseno area of western Kenya, intercropping largely entails short fallow periods and is deeply entrenched among farmers who exploit the diversity of compatible species like cereals and legumes, interspersed with African leafy vegetables [Abukutsa-Onyango, 2007] and various fruit/trees that include local mangoes, avocadoes, bananas, and/or guavas. However, where perennials are involved, no distinct fallow period can be isolated; and a good example is when tea (*Camellia sinensis*) is intercropped with traditional vegetables [Maritim, 2006]; and Bananas (*Musa Spp.)* with Coffee as a livelihood source of food and substantive income for the farm family [Bagamba *et al.,* 2010]. "Enriched Fallows" [Sanchez, 1999] are those where certain shrub species like artemisia are grown at predetermined plant densities to produce high-value products such as medicine or woodfuel for economic benefits

A major advantage of an agroforestry system with shrub hedgerow intercropping 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. This allows farmers to achieve sustainable production for a longer period combined with conservation of the resources on which that productivity depends [Young, 1989]. Better use may also be made of crop residues than the burning following harvest as is currently practiced by many farmers in Kenya [Okalebo *et al.*, 1999]. Generally, the ensuing diversification of crop enterprises and fallow periods through AF intercropping within a field provides a buffer against consequences of environmental degradation [FAO, 2009]. Moreover, the potential of intercropping to control both ordinary weeds [Itulya, 1998; Chabi-Olaye *et al.,* 2005] and parasitic weeds such as *Striga hermonthica* in food crops [Rao and Gacheru, 1998; Gallagher *et al.*, 1999] has been aptly demonstrated, specifically in enhancing land use efficiency (LUE) in fallows through less or no usage of herbicides. This may be particularly important in AF intercropping systems with limited capacity for external inputs application, to save on labour or input costs through desired or predetermined component interactions.

Under AF intercropping systems with maize, the application of inorganic fertilizers is a major requirement for increased crop production [Okalebo *et al.*, 1999] and hence planning for timely and adequate fertilization to cover the full needs of all component crops can be challenging not only for resource poor farmers, but also because these needs must be met for optimal results [Muriuki and Qureshi, 2001]. Such recommendations vary, but key aspects to successful intercropping include detailed planning, timely planting of each crop, optimal spacing (spatial arrangements) with the right plant densities, effective weeds and pest control [Sullivan, 2003]. An informed choice of crop mix options, harvesting at recommended maturity dates and good post-harvest handling practices are also critical for optimum yield.

2.2 Intercropping Potential in Maseno

Maseno area of western Kenya is a tropical sub-humid region characterised by three to five dry months in a year; and traversing three distinct AEZ's, namely Upper-Midland(UM), Upper-lowland(UL) and Lower-Highland(LH) temperature belts defined according to the maximum temperature limits within which the main food crops can flourish [FAO, 1978]. Intercropping in the context of AF is one of the main land-use systems in the region, where according to the KNBS [2005] over 90% of households are engaged in crop farming activities, the highest percentage among all regions in the country.

Agroforestry shrubs or trees grown in medium to upland AEZs' of western Kenya in general play important roles in homesteads that include the shading of other cash crops particularly Tea and Sugarcane; serve as herbaceous cover crops [Amadalo *et al.*,2003] , windbreaks [Nair, 1993] and provide remedial medicinal concoctions [Jeruto, 2008]. Intercropping is historically a traditional African practice [Karim and Savill, 1991] and is a basic way of enhancing livelihood and biodiversity of an agro-ecosystem at farm level through interaction between the individual crops; more often without the practicing farmers' express knowledge or appreciation [Ghosh, 2004]. It is also a strategy for diversifying food production and household income [Kimaro, 2009]. Like the *Faidherbia* trees intercropped with sorghum and millet in Sahelian agriculture as source of wood fuel [Boffa, 1999], artemisia shrubs can also provide ready wood fuel after extraction of leaves, thus enhancing land use efficiency at farm level in western Kenya. For rural farm families in the region, intercropping often involves maize and a legume, with the maize component being considered as the main crop contributing to food security; while the legume component mainly beans, is a readily available source of on-farm dietary protein. While successful AF intercropping systems should provide a total yield value greater than if the crops are growing separately, the planting patterns commonly in practice at the moment may be motivated by availability or not of family labour for convenience in sowing, weeding, and harvesting than by a need to optimize on yield [Macharia and Shiluli, 2003] through proper spacing.

Small scale farming at Maseno is rarely considered as a business; since most households rely on the farm for only about 15% of their cash income [Amadalo *et al.,* 2003], and many previous studies in the region have not appreciated that small scale farmers are more concerned with tangible monetary benefits accruing from their intercropped farms. Many such studies have thus provided varying and unreliable projections on yield advantage of AF intercropping systems incorporating maize with shrubs, through pseudo-adoption and the desire of respondents to please researchers in return for handouts or a networking opportunity [Kiptot *et al.,* 2007]. In particular, the potential effects of intercropping artemisia and maize on yield of both crop components in regard to opportunity costs have not been documented in the region. Considering that most labour at farm level is provided by women [Onyango, 2002] or family labour, higher income from farming to sustain food security could also be in terms of foregone labour costs. Replacement value of agroforestry [Moseley, 1994] may thus account for the time and inputs used on a cocktail of various combinations of the intercrops grown either simultaneously or sequentially within pre-determined fallow periods.

Due to the basic desire by small scale farmers to meet their food security needs, cultivating at least twice in a year is a normal farm practice in Maseno area and the fallow period therefore becomes an integral part of the production process, when evaluating relative yield advantage and/or disadvantages especially in sequential systems of intercropping. In addition, conditions that favour development of successful smallholder AF intercropping systems include: Available planting material of appropriate species for the AF system, management experience with shrub/tree planting and tangible, accessible markets [Scherr, 1995].

2.2.1 Intercropping Yield Dynamics

Generating a cash income from medicinal plants is extremely important to household food security for farming communities with marginal socio-economic conditions [Cole and Bustan, 2009] as is obtaining in many areas of western Kenya. Since most arable land is under cultivation in the region [Jaetzold *et al.*, 2005], future increase in agricultural productivity may well depend on multi-functional agriculture, through diversification or intensified AF intercropping rather than expansion in area under monoculture production [FAO, 2005]. In addition, AF systems may harbour more soil invertebrates than monocultures, implying little potential for C sequestration in pure stands of either artemisia or maize, apart from the inherent lack of biodiversity [Monneveux *et al.*, 2006].

Furthermore, rainfall is the single most important factor affecting both intercropping yield and biomass accumulation by crops in the tropics, and precipitation patterns within seasons have changed to the extent that cases where drought occurs at critical growth stages, and heavy rainfall at crop maturity when water is least required are becoming common [Birech *et al.*, 2008]. In such scenarios, intercropping logically provides a lesser risk of total crop failure than pure stands of any annual food crop.

Crop yield variability however comes from complex interactions between the environment, spacing, management, progenitors and abiotic factors that occur across a field [Baumann *et al.,* 2002] of intercrops. For example, artemisinin has phytotoxic activity, even on the artemisia plant itself [Lydon *et al.*, 1997]. Kato-Noguchi, [1999] reported further that germinating maize seeds also have at least three allelochemicals which may affect the growth or germination of other plant species grown in association as intercrops like lettuce (*Lactuca sativa* L.), Oats (*Avena sativa L.*), and Ryegrass (*Lolium multiflorum*). Other studies in western Kenya indicate that unlike intercropping, prolonged monocropping enhances soil salinity in many of the already fragile environments [Musyimi, 2005]; while Intercropping improves the microclimate or soil temperatures [Oseko, 2007; Ouma and Jeruto, 2010].

As a measure of the relative biological and economic yield potential of AF intercropping, Moseley [1994] proposed that the Replacement Value of Intercropping (RVI) by Van der Meer [1989] could be modified to include fallow periods, and variable costs for labour and inputs used in the production process of the intercropping system, to result in Replacement Value of Agroforestry [Moseley, 1994]. There is however scarce scientific evidence from sub humid regions on interactions between inter-plant competition with positive effects of shrubs and food crops, where interpretation of specific results is often complicated [Van Noordwijk *et al.*, 2004]. In addition, Reyes [2008] observes that even though improved AF tries to take the best out of the traditional Agroforestry methods and combine them with new scientific findings and innovations, farmers will not shift automatically to alternative farming systems unless there is a good prospect for monetary gain. This may help to explain why the potential effect of intercropping on yield of subsistence maize in western Kenya has not been appreciated, despite the existence of an elaborate catalogue of developed technologies that the farmers could use over the years. There also may be an emerging trend for small scale farmers' growing apathy to livelihood from maize monocropping or intercropping with legumes as a result of perpetual under-productivity and erratic rainfall due to the climate change phenomenon; causing frequent failure especially of the legume component thereby compromising farm level food security.

2.2.2 External Input Application

In general, both intercropped and monoculture maize in most parts of Western Kenya is grown under low-input application regimes [Smale and Jayne, 2003]; and there are various limitations imposed by overdependence on external inputs, scarce resources and social structures in the agricultural production process that affect fertilizer use, choice of suitable intercrops and timeliness of planting [Beets, 1990]. In cases where maize is the main intercrop, inorganic P from commercial sources may still be needed to realize increased maize yields [Okalebo *et al.,* 1999], and hence a challenge for resource poor farmers. Furthermore, the use of some compound fertilisers like Di-ammonium phosphate (DAP) commonly available in the market to correct soil Phosphorous (P) are low in nitrogen than the Phosphorus [Shiluli *et al.,*2003] and hence can increase soil acidity and facilitate net mining of soil nitrogen (N), instead of improving soil fertility.

According to Ståhl *et al.,* [2005], shrubs with prolific biomass producing ability have the potential to increase both soil C and N pools and thus enhance soil organic matter even in sequential systems of intercropping with nutrient-poor soils, but this is only true when other nutrients like water are not limiting. Furthermore, benefits only accrue to crops in a subsequent season since the main transfer pathway is due to root senescence and fallen leaves [Ledgard and Giller, 1995]. Even though *Artemisia spp* shrubs may not contribute substantially to soil moisture conditions; they alter N cycling rates [Darrouzet-Nardi *et al.*, 2008]; add organic matter to the soil [Griffee and Diemer, 2006]; can grow profitably without commercial fertilizers [Genders, 1994] and hence may substantially reduce the need for soil fertility improvement in cases of denuded environments.

Once soil P deficiency is overcome mainly through application of commercial fertilizers, higher crop yields and net benefits can be realised from the nutrient-depleted soils of western Kenya [Ndung'u *et al.*, 2006; Wasonga *et al.*, 2008] through intercropping maize with some shrubs. Odhiambo and Ariga [2001] further report that intercropping practices entail minor adjustments in the current farming systems of western Kenya, without the necessity of additional N application. While shrubs may not be a substitute for external input application as a means of sustaining intercrop productivity, there are aspects of the production process in a cyclic period of intercropping that may be considered mundane by the small scale farmer. One such aspect is the lack of adequate information on fallow species for diversification and diminishing fallow periods in response to the high demographic pressure in Maseno area of western Kenya.

2.2.3 Artemisia Fallows

According to Brown *et al.*, [2005], the main factors which influence the choice of crop mixtures hence fallow species in western Kenya, to ensure sustainability of any AF intercropping system include the physical characteristics of the land available for cultivation. This may presumably entail the availability or not of fallow species and periods. The traditional farming system of rotational bush-fallow, also known as Slash and Burn agriculture was once considered to be in equilibrium with the agro-ecological conditions of western Kenya [Barrow, 1989]. However, with the increasing demographic pressure, farmers in the region have drastically reduced the fallow periods [Otsyula and Nderitu, 1998] or even abandoned them completely in the more densely populated upland areas where traditionally, continuous maize+bean intercropping is the norm in farm practice. Both improved and enriched fallows are widely used in western Kenya with varying degrees of uptake [Place *et al.*, 2004]; while the fallow periods commonly promoted with AF shrubs extend upto 3 years in duration [Amadalo *et al.,* 2003]. Considering that either raw or processed artemisia has potent medicinal properties and numerous other agroecomic uses, artemisia *spp* qualifies as an enriched fallow species. For example, the phytotoxic activity of artemisinin [Lydon *et al.*, 1997] implies that artemisia is a candidate for biological or value-added herbicides. In addition, non-legume shrubs belonging to the *Asteraceae* family like artemisia, collectively called ‘daisy fallows’, may further provide lessons for further development of improved fallows [Sanchez,1999].

When land is fallowed due to the need to restore soil fertility after a period of cultivation, shrubs can be grown to speed up the process: The preferred shrubs should be able to add organic matter to the soil [Mtambanengwe *et al.,* 2007] whereby artemisia becomes an ideal candidate. While evaluating intercrops in both spatial and temporal arrangement of time, Hiebsch and McCollum [1987] proposed the Area-time Equivalent Ratio (ATER) that effectively captures the intervening fallow periods in sequential AF intercropping systems. In Tasmania field trials (2000, 2001 and 2002), incorporation into the soil of dry leaves of artemisinin-rich *Artemisia annua* concurrently reduced weed emergence (between 65 and 80 %) and weed dry weight (>80 %) with a fallow period of 45 to 60 days [Laughlin, 1994]. Artemisia as a component crop in AF intercropping systems can also be grown bi-annually in sub-humid areas [Ferreira and Janick, 1995]; thereby reducing fallow periods considerably to a maximum of 2 months (60 days) to suit the rainfall patterns and high demographic pressure on demand for arable land in western Kenya.

According to Kwesiga and Coe [1994], increasing the fallow period in Maize + Sesbania intercrops decreases the effectiveness of inorganic fertilizers; and short fallow rotations of 1–3 years using *Sesbania sesban* have a potential to increase maize yield even without fertilizers [Kwesiga and Coe, 1994]. Increased cumulative crop yield per unit land area of sustainable AF systems hence profitability can also be realized by shortening the fallow period [Swinkels *et al*, 1997; Van Noordwijk, 1999]. However, Yield advantage of selected artemisia + maize intercropping patterns as an AF Practice within a predetermined 'fallow period' in an annual growth cycle has not been studied. Promotion of artemisia+maize intercropping components to complement other enriched fallows or the maize+bean intercrop system could thus form the basis of a sustainable AF intervention, in addition to enhancing on-farm biodiversity in western Kenya. The effect of intercropping artemisia+maize using different spacing regimes on quality of artemisia as manifested in artemisinin yields or % content has not been recorded.

2.2.4 Interplant Competition

In AF systems there are socio-economic, ecological and biophysical interactions between the different components; and the productivity and efficiency of arable land use potential in any AEZ is therefore determined by the extent of interplant competition through various interaction levels [Van der Meer, 1989]: Competition can occur between the same species, called intraspecific competition, or between different species, called interspecific competition. Ultimately, any recommended AF intercropping system involving maize as a food crop and artemisia as a medicinal shrub will entail effective application of Good

Agriculture Practices (GAPs) for minimum pesticide usage, to ensure the least possible impact on the environment; and yielding a product that can be accurately traced from the field where it is grown to the consumer [WHO, 2003]. These practices should also be geared towards minimizing competition for plant growth resources, and enhance or compliment any positive component interactions that may exist. Willey and Rao [1980] demonstrated that the Competitive Ratio (CR) could be useful in comparing the competitive ability of different crops, measure competitive changes within a given combination and determine what competitive balance between crop components is most likely to give maximum yield advantages.

It is thus possible that intercropped plant species in any AF system may not coexist productively if they share the same niche adversely. While Niche differentiation is not the only means by which coexistence is possible between two competing plant species [Spitters, 1983]; it is an important agroecological paradigm that may account for species coexistence in AF systems and enhance biodiversity. However, the effect of intercropping maize and artemisia components on basis of above ground competition for growth resources as a function of productivity and land use efficiency has not been documented.

2.3 Maize Component

2.3.1 Origins of Maize

Early forms of maize were very small with minute kernels, and in about 300 years from the 15th Century onwards, maize had become an important food and fodder crop in temperate, tropical and subhumid regions of the world [McCann, 2007]. Maize is among the domesticated crops into Africa for intercropping with indigenous crops like pearl millet (*Pennisetum typhoides*) and sorghum (*Sorghum bicolor* L.) through a cyclic rotation for a few years before the land is left to fallow [Reyes, 2008]. Thus, the propagation and maintenance of local maize varieties was shaped by both farmer preferences and natural selection processes. Local varieties may be a key source of genetic biodiversity upon which farmers cultivate them because of household tastes and preferences, or risk aversion towards newly introduced varieties [De Groote *et al.,* 2004]. While maize in general is the staple food crop of western Kenya, local varieties have exhibited superior qualitative traits (i.e. early maturity, disease resistance, and good eating qualities) and they may thus provide important sources of traits required for local adaptation and sustainability [Anjichi *et al*., 2005].

By providing farmers with seed of a late-maturing white H_1 maize variety each season, as replacement to continuous use of traditional varieties from previous crop harvests, the colonial government in Kenya after the 2nd world war sped the transition from millet intercrops to a monoculture maize-based food economy [Gerhart, 1975]. CIMMYT is currently fostering accessibility to farmers of quality seed from promising cultivars, by ensuring the germplasm used to produce such seed complements the agricultural ecology of target areas [Hassan *et al.,* 2001]. Maize hybrids generally have superior quantitative traits (i.e. height, grain yield) as long as their agro-ecological requirements are met, but achieving their potential by rural farmers in Kenya is a big challenge because of poor management, a lack of (requisite) agricultural inputs, unfavorable biotic and abiotic factors, or a combination of these factors [Mwololo, 2010].

2.3.2 Botany and Ecology of Maize

Zea mays L. is an erect fast growing and short-lived annual growing commonly to 2–3 m in height, usually with a single main Culm and several lateral branches in the leaf axils in the upper part of the plant that develop more prominently [McCann, 2007].The leaves alternate with broad sword-shaped blades and parallel veins with a prominent mid-rib, all of which tend to lose turgidity as the plants approach physiological maturity. The main Culm produces at least 8 leaves; with tropical hybrids producing 30 - 48 leaves [Paliwal, 2000]. The main roots are supplemented with aerial brace roots, which protect the plants against water lodging. Flowers are monoecious, born in separate parts of the plant where female flowers or ears arise from auxiliary buds and male flowers (tassels) arise from the apical stem. Maize is wind pollinated but both self and cross pollination usually occurs or can be induced. Self pollination is needed for inbred development while controlled cross pollination is mandatory for hybrid seed selection; and the production of the hybrid seed requires the development and maintenance of inbred lines and subsequent controlled crosses to produce the commercial seed available in markets. Shed pollen usually remains viable for 10 to 30 minutes, but can remain viable for longer durations under favorable conditions [Paliwal, 2000]. Maize is a C_4 plant with a high rate of photosynthetic activity and on a per plant basis its multiplication ratio is 1: 600 – 1000, thus offering the highest potential of carbohydrate production per unit area per day [Paliwal, 2000].

Tropical environments account for 45% of the total area under maize cultivation in developing countries and highland environments constitute 8% of the total area under maize cultivation in the developing world [Byerlee and Eicher, 1997]. Maize can be grown at altitudes at varying altitudes and requires an increasing long growing season with increasing altitude, normally maturing in 90–120 days, or as quickly as 80 days with very short season cultivar [Hassan *et al.,* 2001] and the plants' seasonal leaf and grain yields may be reduced where rainy seasons are short. The plant grows best in 600–1,500 mm rainfall environments and has a high requirement for water but drought-escaping short season cultivars have been developed for regions with short rainy seasons. Maize requires a well-prepared seed-bed and seeding rates vary with cultivar and moisture regimes, but in western Kenya planting density for maize is maintained at approximately 44,000 plants ha^{-1} [Macharia and Shiluli, 2003].

Manual hand seeding of maize is used in western Kenya by small scale farmers; unlike precision planting equipment which achieves uniform plant stand but uneconomical due to small land sizes. Maize responds strongly to fertiliser application in denuded soil conditions whereby rates of 60 kg N (3 **X** 50kg bags CAN) and 60 kg P_2O_5 ($2^1/_2$ 50kg bag, DAP) per hectare are recommended for use in rainfed crops, but maize in western Kenya is often grown under low phosphorus and nitrogen conditions [Wasonga *et al.*,2008]. Bed/row spacings range from 75–120 cm apart and seed is planted upto 100mm deep depending on soil type. Maize is adapted to well-drained soils of neutral to mildly alkaline reaction, but will grow down to pH 5.0 providing that Aluminium saturation is low in acidic soils [Gudu *et al.*, 2005]. There is a direct relationship between yield of maize and rainfall after 4 to 5 weeks of growth; and minor drought or water logging during specific physiological stages can reduce maize yields substantially: Claassen and Shaw [1970] found that four days of visible wilting just before tasseling can reduce yields by 10 to 25%, and four days of wilting between the boot stage (only a week prior to tasseling) and the milk stage may reduce yields by 50% or more. Tsubo *et al.* [2005] also produced a simulation model showing that initial soil water content has the greatest influence on maize intercropping productivity as an abiotic stress factor [Ogindo, 2003] but generally, the crop is best sown at the start of wet seasons in sub humid tropics.

2.3.3 Cultivation of Maize in Western Kenya

Western Kenya has a bimodal rainfall pattern, the long rains (LR) and short rains (SR) and therefore ideal for early maturing maize crop varieties [De Groote *et al.,* 2004]. Date of sowing maize is dictated by many factors including weather, crop production system and labor constraints faced by the farmer whereby the crop is generally grown as the overstorey crop in a Cereal+Legume or vegetable, tuber-based intercropping system. Farmers have an aesthetic attachment to maize cultivation and consumption now popularly referred to as the "Maize Syndrome" where they have over the years widely adopted improved crop varieties and post harvest handling practices. Maize is the staple food crop, and accounts for about 3% of gross domestic product and 25% of agricultural employment [Mwololo, 2010]. However, average yields are far below sustainable levels [Smale and Jayne, 2003], thus creating serious food deficits especially when rain precipitation is now unpredictable or land sizes are small to the extent of not yielding any advantage to monocropping. Both intercropped and monoculture maize in Western Kenya is grown by small to medium-scale farmers who cultivate about 2.5 ha of land or less under low-input application regimes especially for the improved cultivars, where most households produce maize that can hardly last 5 months after harvest [Amadalo *et al.,* 2003]. Among the factors that contribute to stagnation in productivity may include abiotic pressures due to agricultural intensification.

There is a serious soil P deficiency in western Kenya [Okalebo *et al.,* 1999; Ndung'u *et al.*,2006], and thus achieving optimum yields from maize monocrops is constrained by inability of small scale resource poor farmers to afford commercial Phosphate fertilizers [Wasonga *et al.*, 2008]. Attention to weed control is also essential until canopy closure, and a major constraint to maize cultivation is the parasitic weed *Striga hermonthica* [Odhiambo and Ariga, 2001] and high demand for uprooting labour in the season during peak invasion of the weed. Herbicides for farmers who can afford and manual techniques are commonly used to achieve weed control of such other species as Couch grass, *Chloris gayana, Cynodon spp,* and *Pennisetum clandestinum.*

Maize is also susceptible to biotic stress factors that include stalk borers (*Busseola fusca and Chilo partellus*) [De Groote *et al.,* 2004], maize streak virus (MSV) transmitted by *Cicadulina* leaf hoppers [Makumbi, 2005]; and common smuts caused by *Ustilago maydis* that reduces grain yield considerably [Williams and McDonald, 1983]. These factors may not only cause complete loss in yield and income from maize monocrops, but also make chemical plant protection necessary thereby causing environmental impacts that do not conform to Good Agricultural and Collection Practices (GACP) in general [WHO, 2003]. Chemical control of these pests and diseases in absence of such agronomic practices as intercropping may thus increase the cost of production by attracting extra financial input to the already resource poor farmer. Important post-harvest pests of maize in Kenya include the grain weevil (*Sitopholus zeamais*) and the larger grain borer (*Prostephanus truncates*) while poisonous aflatoxin produced by the fungus *Aspergillus flavus* in poor storage conditions are of particular interest for maize consumers.

In western Kenya, maize can yield upto a maximum of 35 ninety Kg bags Ha^{-1} with recommended agronomic practices [Shiluli *et al.*, 2003] especially for the newly bred varieties that may have significantly high nitrogen use efficiency [Sigunga,1997], good tolerance to low N_2 [Makumbi, 2005] and *Striga hermonthica* like KSTP maize [Khan *et al.*,2006]. Maize yields under farmers' conditions in the region average 1.3 t ha^{-1} [Hassan, 2001], or less than 25% of the potential yield of 5 t ha^{-1} [Tittonell *et al.*, 2005] under rainfed conditions. Since yield is the main factor used for maize production estimates in Kenya, Rojas [2007] reports that declining trends for productivity and a constant trend for area under cultivation will compensate for each other in the medium-term.

2.3.4 Maize in Intercrops

The great diversity of AEZs and farming systems under which maize is grown may be unmatched by other cereal crops in the world. In AF systems, maize can be interplanted with legume fallows such as *Lablab purpureus*, *Crotolaria spp* and *Sesbania sesban* which are widely advocated in western Kenya for improving soil fertility and structure, in order to reduce

N-fertilizer requirements for subsequent maize crops [Amadalo *et al.,* 2003]. When maize is intercropped with high-value, commercial fodder leguminous shrubs like Silverleaf (*Desmodium uncinatum*), ovipositing stem borer females are repelled, and striga weeds are suppressed by more than 40 times [Khan *et al.,* 2006]. Odhiambo and Ariga [2001] further reported that pure maize stands produced significantly lower grain yield than other intercropping treatments with beans, due to higher striga weed emergence in the former; while intercropping maize and beans in the same hole had the highest grain yield of 78.6% above yields in pure maize stands. Furthermore, when intercropped with maize, such species as *Crotalaria* and *Mucuna* have reduced damage to maize in Kenya from the lesion nematode *Pratylenchus zea* compared with maize monocultures [Arim *et al.,* 2006].

Studies by Kariaga [2004] in western Kenya also established that sole maize produced the highest runoff while maize inter-cropped with cowpeas (*Vigna unguiculata* L.) produced the lowest runoff hence a better protection of the soil against erosion. Dissemond and Hindorf [1990] also reported a significant reduction in stem borer population by intercropping maize with cowpeas. While intercropping maize with sesame (*Sesamum indicum* L.) as a cash crop, Mkamilo [2004] found that it is unproductive for farmers to grow sesame as a sole crop due to the high risk of seedling mortality from water-logging, snails, or the sesame flea beetle (*Alocypha bimaculata*); but maize yields can be maintained while producing an important cash crop to supplement smallholder income in southeast Tanzania.

Maize can also be planted as an intercrop with many other food crop species, that include Okra [Oyewole, 2010], Cassava [Olasantan and Lucas, 1996]; Pumpkin (*Cucurbita spp.*), Pigeon pea (*Cajanus Cajan*), Groundnut (*Arachis hypogea*) and Cucumber (*Cucumis sativa*) [Mariga, 1990]; and is widely used in Alley systems with hedgerows of Artemisia and other valuable shrub species in China [Ellman, 2006].

2.4 Artemisia Component

2.4.1 Origins of Artemisia

Artemisia annua L. has been kept at the Chelsea Physic Garden in London since the mid 1700s [Frodin,2001]; and was first mentioned in botanical literature in 1739 where fossils confirm that artemisia is an annual herb native to Asia, as part of the Steppe vegetation in parts of Chahar and Suiyuan provinces of China [Ferreira *et al.,* 1997]. Central Asia is therefore its center of diversification, while the Mediterranean region and North West America are two secondary centers of origin [Valles and McArthur, 2001]. The original source of germplasm is not documented and may have been derived from several sources and bulked by seed and vegetative propagation. One theory on the ethnobotany of the crop traces it from Greek mythology where *Artemis,* meaning literally "she who heals sickness" was the goddess of the woods and the wild, which as legend states, derived so much good from plants therein to be named after her [Ferreira *et al.,* 1997] for easing childbirth in women: Goddess *Artemis* was the source of a controversy with sculptors in biblical times when Paul went to Ephesus (Book of ACTS 19: 23-41). Artemisia shrubs are known to produce the active ingredient 'artemisinin' in use since 340 AD to cure chills and fevers in traditional Chinese medicine [Ferreira and Janick, 2009]. The plant has since been domesticated in many countries including Madagascar, Vietnam, Tasmania, the Americas and Europe. The plant is now widely dispersed throughout the sub-humid regions of the world and some taxa are toxic or allergenic while others are invasive weeds which can adversely affect food crop harvests [Tan *et al.,* 1998]. The plant has most recently been introduced for commercial cultivation in Kenya by EABL to supply the pharmaceutical value-chain industry; including ICIPE [2005] that has recently focused on developing and testing unfractionated whole plant extracts made into tablets, with promising clinical results.

2.4.2 Botany and Ecology of Artemisia

Artemisia annua L. is so named because it is almost the only member of the genus *Artemisia spp with* an annual growth cycle; and is a large herbaceous shrub often reaching about 2.0m in height, single-triple stemmed with alternate branches that range from 2.5 to 5 cm in length; with aromatic leaves that are deeply dissected [Ferreira and Janick, 2009]; the plant has a short taproot and aggressive fibrous roots. Duke *et. al*., [1994] further observe that the foliage is fernlike, with alternate leaves, and of a papery texture; Herbaceous involucral bracts are present; Receptacles are convex and entire plant bodies covered by hairs. In addition, cypselas are inferior and unilocular, oblong and mostly brown, whereby basal leaves have slender petioles, middle leaves are pinnate, the upper leaves are sessile and less divided, and the leaf base withers at florescence [Hayat *et al.,* 2009].

The plant is a vigorous, erect annual (sometimes bi-annual) herbaceous species where non-glandular T-shaped trichomes and 10-celled biseriate glandular trichomes occur on leaves (that are easily detachable), stems, and inflorescences [Ferreira and Janick, 2009]. These glandular trichomes are more prominent in the corolla and receptacle florets than in leaves, stems, or bracts and there is strong evidence that artemisinin is sequestered in these trichomes [Duke, 1993]. Furthermore, although these glands are present since the early stage of development on both leaves and inflorescences, artemisinin increases at anthesis, suggesting that it accumulates as the glands reach physiological maturity, a stage which coincides with the end of cell expansion in floret development [Duke *et., al*., 1994]. The flowers are tiny, numerous and as is common to all taxa of the tribe Anthemideae, they are perfect and can be either fertile or sterile while fruit ovaries contain minute seeds each (1000 seed weight = 0.03g) about 1 mm long with a creamy white endosperm [Ferreira *et al.,* 1997]. As for the leaves, Marchese *et al.,* [2005] observes that in spite of the existence of parenchyma cells forming a sheath surrounding the vascular tissues, the cells do not contain chloroplasts or starch, suggesting that leaves of *A. annua* have a C_3 photosynthetic mechanism; but the existence of parenchyma bundle sheaths with little differentiation of the mesophyll cells in artemisia leaves may represent a transitional stage in the evolution of C_3 to C_4 photosynthetic pathway for the plant [Marchese *et al.,* 2005].

Artemisia naturally cross-pollinates by insects and wind action, which is unlike the *Asteraceae* which mainly self pollinates [Duke *et., al*., 1994]. The plant thrives in many temperate to sub-tropical ecologies (Min. 10^0C, Max.35^0 C), but is considered a short-day plant [Ferreira *et al.,* 1997] and some genotypes can present a requirement for low temperatures to accelerate flowering thus indicating a photoperiod - temperature interaction. The critical photoperiod seems to be about 13.5 hours, and with regard to flowering, *A. annua* genotypes with similar geographical origins can present variations in the behaviour under the same photoperiod and temperature conditions [Marchese *et al.,* 2002]. Altitude range occurs at 1000-1500m a.s.l [Ferreira *et al.,* 1997] but generally found between sea level and 3600 m. According to studies commissioned by Technoserve Inc., [2004] in East Africa, Artemisia is an annual plant with a growth cycle of about 180 days for cultivation (80 days in the nursery and 100 days in the field); the reported annual rainfall range for growth is 300-1500 mm with the optimum between 500-1300 mm and distribution is more important than absolute amounts especially during 2-3 months after transplanting. Artemisia can withstand dry conditions once established, except that low temperatures and any moisture stress in the early stages or water logging towards maturity tends to reduce production of leaves and induce flowering [Ferreira *et al.,* 1997].

The reported optimum soil pH range for artemisia growth is 5.5 – 7 [Laughlin, 1994] with good water retention capacity and not liable to water-logging. The plant prefers light to medium textured (sandy and loamy), well drained or dry soils and thrives in fertile soils. However, artemisia will grow in nutritionally poor soils where Genders [1994], observes that the plants are longer lived, hardier and more aromatic when grown in a poor dry soil to yield significantly on the active ingredient. The plant can withstand dry conditions once established, but any moisture stress in the early stages tends to induce flowering and reduce production of leaves. In addition, there are reports that lack of potassium (K) might increase rather than decrease the artemisinin content of the leaves [Ferreira, 2007]. Artemisia farmers could thus realize more artemisinin productivity under a mild K deficiency, while saving on potassium fertilization.

Slopes steeper than 15% are unsuitable, though once established *A annua* gives reasonable protection against soil erosion [Technoserve Inc., 2004] due to its vigorous fibrous roots system. Unlike maize, artemisia does not need planting fertilizer and pesticides to break even [Dalrymple, 2008]. This could be a very important consideration for farmers practicing GAPs [WHO, 2003], organic farming, or for resource-poor farmers with low capacity to afford commercial fertilizers and using artemisia as an enriched fallow species. In addition to the highlands of Kenya, the plant has been introduced for commercial cultivation in countries such as Brazil, India, Mozambique, Thailand, Tanzania, and Uganda, all in medium to high altitude regions [Ferreira *et al.*, 2005]. The average yield of *A. annua* varies between 1.5 to 2 tons of dried matter ha^{-1} and the average content of artemisinin (the active ingredient) varies with the seed quality, climate, altitude, soil, farmers know-know, and planting density [Laughlin, 1994].

2.4.3 Cultivation of Artemisia in Kenya

Suitable areas in East Africa are cultivating a newly developed hybrid (F1) seed from Médiplant, Switzerland [Delabays *et al.*, 2001]; which is insensitive to day length and shows superior performance in contents and yields compared to the Asian genotype [Heemskerk *et al.,* 2006]. The plant is grown for the pharmaceutical industry in Kenya where preliminary results indicate that given its climate, Kenya has the potential of producing the crop with yields of the active ingredient higher than that obtained from the varieties cultivated in China and Vietnam, two countries which currently provide the bulk of global artemisia requirements [Ellman, 2006]. This comparative advantage depends on other dynamics of the artemisia derivatives' supply chain and market demands. As with all medicinal plants, Good agricultural and collection practices for artemisia entail proper cultivation and post-harvest handling techniques to meet quality requirements [WHO, 2003]. Artemisia is not a labour-intensive cash crop but whose cultivation requires close attention to detail, especially at planting and harvesting time. Direct drilling is not recommended, due to the tiny seed whereby artemisia plants are then vegetatively propagated from a single node stem cutting cultivation [Ferreira *et al.*, 2005] thus presenting a comparatively economical way of initiating cultivation. According to the EABL [2005], good and early land preparation is critical for artemisia cultivation in Kenya well before the rain season to ensure that the soil is not worked when too wet as this will lead to loss of soil structure and poor compaction of the soil resulting in poor plant vigour. As in maize, early land preparation may also be critical in facilitating weed control and an important factor in growing artemisia successfully. As standard agronomic practice, farms on steep terrain may require the plants to be established on laid out terraces particularly where soils are heavy and susceptible to water logging. Vegetative strips [Mercado and Laput, 2008] or ridged terraces on steep land for soil and water conservation are made wide enough to maintain their shape after heavy rain and high enough to keep the roots of artemisia free from effects of water logging.

Cultivation takes a minimum of 4 months while extraction, processing and manufacturing of the final product requires at least 2–5 months depending on the product formulation. According to Ferreira *et al.,* [2005], harvest timing is critical, as artemisinin content tends to climb steeply during late active growth, then to plateau briefly and finally, to fall off sharply once flowering has initiated, with its corresponding leaf drop.

Leaf biomass has been shown to increase significantly with application of Foliar feed [EABL, 2005]. An increase in artemisinin concentration by upto 30% from sun drying whole plants of artemisia for 20-30 days after harvest were recorded by Laughlin [1994], and this is currently a standard post-harvest handling practice in Kenya. Field production of artemisia is presently the only commercially viable method to produce artemisinin the active ingredient, because synthesis of the complex molecule is uneconomical [Woerdenbag *et al.* 1991] and the main challenges in Kenya are to increase yields from each land unit, increase leaf biomass (over 1 tonne per acre), and increase artemisinin content in leaf (over 1%) [Nigel 2004]. Despite the low productivity of *A. annua* (1.5–2.5 tonnes ha^{-1}) and artemisinin concentrations (<1 %), production of upto 14kg of artemisinin ha^{-1} is possible [Kindermans *et al.,* 2007]. Average global artemisinin production after extraction stands at 0.6% of leaf biomass [Ferreira *et al.,* 2005], representing artemisinin yield of 12 kg/ha but a field trial of a late flowering clone of artemisia from Switzerland [Delabays, *et al.*, 2001] produced an average of 20kg artemisinin ha^{-1} of land under cultivation .

2.4.4 Artemisia in Intercrops.

Artemisia as a medicinal shrub has successfully been intercropped in AF systems with various field crops like maize, cowpeas and groundnuts in China, Iran, and India respectively [Ellman, 2006]. Artemisia has also been successfully grown as an intercrop with coffee seedlings in Tanzania to result in a much lower population density of Artemisia than usual, but will minimise shading coffee: When grown in one line between the coffee rows, there was no significant shading effect on stumped coffee [Griffee and Diemer, 2006]. This trial further showed that artemisia significantly adds organic matter to the soil and is a cheaper method of coffee production since pruned coffee must still be weeded, irrigated and sub-soiled; while artemisia gives at least a return in an otherwise barren year for the coffee[Griffee and Diemer, 2006]. The plant has also been found to not only control soil erosion but also repel leaf miners in the same Tanzanian coffee plantations [Technoserve Inc., 2004].

Artemisia was intercropped with Lettuce and exhibited allelopathic effect on the germination and initial development of lettuce seedlings [Magiero *et al.*, 2009]. Artemisia also suppresses some weeds through similar allelopathic effects [Duke *et al.,* 1987; Lydon *et al.,* 1997; Mekky, 2008]. Studies on component interactions at a field of grasses in California USA indicate *Artemisia spp.* Shrubs competitively reduced resident herbs [Darrouzet-Nardi *et al.,* 2008]: Farmers in western Kenya could thus 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. Artemisia is not only medicinal but has the potential to reduce weed pressure and restore soil organic matter (SOM) that was reduced during a previous cultivation phase [Laughlin, 1994]. This qualifies the shrub as an enriched fallow species in an AF intercropping system. *Artemisia spp* with great local potential for exploitation in the agricultural industry further include it's use as a natural pesticide in home gardens which consist mainly of vegetables, fruits and fodder AF systems [Sunwar, 2003].

2.5 Component Interactions

Intercropping is the practice of cultivating two or more crops on the same land unit simultaneously or sequentially, and hence a space, time and labour dependent form of multifunctional agriculture. Consequently, intercropping creates a type of component interaction between two or more individual plants that may either reduce the vigour of one or all of them; or have a significant positive impact on the growth rate and yield of the different species used in intercropping [Dhima *et al.,* 2007]. As compared with monocropping, one important advantage of any intercropping system is the resultant increase in productivity per unit area of land in spite of competition for nutrients [Chirwa *et al.,* 2007], partly through the enhanced ecological capital that may accrue from increased biomass for both current and subsequent cropping seasons. Crop selection based on compatibility is vital in well designed intercropping systems and the choice of such compatible crops depends on respective plant growth habits as well as available arable land and other growth resources. An ideal ecological canopy set-up in AF systems should consist of a C_4 over storey and a C_3 under storey for efficient photosynthetic performance and yield [Sikolia *et al.*, 2009]. In addition, any sustainable AF intercropping system will entail a series of deliberate management techniques for suitable intercrops that enable farmers to produce quality products for specific market niches. According to studies by Cadisch *et al.* [2002] in western Kenya, mixing species with compatible and complimentary root and/or shoot growth patterns in fallows leads to a more diverse system and may also maximise above and below ground growth resources' utilization. In this respect, Sobkowiez [2006] 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.

AF Shrubs may exert considerable competition against food crops for growth resources through their below- and above-ground interactions, but combining appropriate agronomic measures like sequential planting and proper choice of companion crops could minimise such effects. Competition exists in AF systems if the growth resources such as water, nutrients and light become insufficient for both shrub and the crop; and to derive benefits from intercropping, interspecific competition for growth factors should be lower than intraspecific competition in single stands [Willey and Reddy, 1981]. There may be significant reductions in the performance and yield of crops particularly when grown in the first few rows adjacent to the shrub rows; and higher yields have been reported when competition between the two species of the mixture is lower than competition within the same species [Van der Meer, 1989].

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 crop yield reductions with increase in distance from the shrub rows have been reported [Netondo, 1991; Chirwa *et al.,* 2007]. Since water and nitrogen are critical nutrients for plant growth and productivity for both the artemisia [Ferreira and Janick, 2009] and maize components [Bänziger *et al.,* 1997] , competition can be more severe particularly in degraded sloppy areas of Maseno with erratic rainfall or flat land with poorly drained soils. However, once site specific optimization of the AF system is effected, the biological merit of intercropping makes it an important conservation farm practice for smallholder farmers, since the system permits nutrient recycling and reduces the need for chemical fertilisers or herbicides in some cases [Van Noordwijk *et al.,* 2004].

Closer spacing both within and between the rows allows for improved distribution of growth nutrients to the intercrops but this may also result in increased competition for other growth resources. On the other hand, wider spacing both between and within the rows reduces competition for water [Ouma and Jeruto, 2010]; and the amount of land available for the intercrops thereby contributing to low productivity. It is therefore important to select intercropping plant species with compatibility in growth resources and space to ensure less competition [Gathumbi *et al.*, 2004]. In humid areas a closer spacing in maize can be tolerated while in drier conditions a wider spacing is required in order to ease competition for moisture [Mtambanengwe, *et al.,* 2007]. Generally, the yield advantage (if any) of AF intercropping compared to monoculture cropping systems may significantly be dependent on cumulative effects of facilitative and competitive component interactions.

2.5.1 Spatial Arrangements

The simultaneous cultivation of different crops on the same piece of land has been described interchangeably as mixed cropping or intercropping, but Ruthenberg [1976] distinguished between mixed cropping and intercropping on the basis of the pattern of crop mixtures. Whichever the case, there is a certain amount of evidence from cereal crops to suggest that changes in spatial arrangements have some yield advantages [Mouneke *et al.*, 1997]. Time of sowing for each crop and plant architecture may thus constitute ideal spatial arrangements for the chosen intercrop varieties grown either simultaneously or sequentially. While working on maize+bean intercrops, Macharia and Shiluli [2003] used a constant maize spacing of 75cm x 60cm and reported that farmers will attain increased bean yield significantly if they adopt systems that utilise the inter-row spaces within the maize rows more efficiently; such spatial arrangements include sowing distinct row(s) of beans between the maize rows. In addition, maize yields have been found to increase away from the hedgerows of such AF species as *Cassia siamea* [Netondo,2001]; *Gliricidia and Fleminga* [Yamoah *et al.,* 1986], suggesting a need to determine specific optimal spacings and spatial arrangements to realize increased productivity of an intercropping system like artemisia+maize.

In humid and sub- humid areas, shrub inter-row spacings range from 2 to 7 m, with 4-6m being the most commonly used [Lawson and Kang, 1990] but the spacing is dependent on rainfall amounts received in an area [Mtambanengwe *et al.*,2007]. Shrub spacings within the rows should be as close as possible and experience with species such as *leucaena*, *Gliricidia* and *Sesbania sesban* indicates that they should be spaced at 10-15 cm or as near as possible to a solid hedge along the row; which favours leaf biomass production over stem or above ground components, provides a more effective barrier to soil movement on sloping lands and creates a better microenvironment for crop growth [Yamoah *et al.,* 1986; Owuor, 1999].

In areas with a bi-modal rainfall pattern such as is obtaining in Western Kenya, correct time for planting is critical for achieving optimal yields. With artemisia, if inter-row cultivation is used to control weeds before the rows close then inter-row and intra-row spacing of 0.5-1.0 m (1-7 plants/m^2) are appropriate [Delabays, 2001]. Generally, depending on the level of agricultural intensification in practice, most practical intercropping systems are a variation of the following [Sullivan, 2003]: Strip intercropping, Mixed intercropping and Relay intercropping. On flat land, shrub rows should be in an east-west direction to reduce shading; while on sloping land, rows must be oriented along the contours in order to reduce soil erosion. Special consideration for spatial arrangements should be taken on sloppy terrain with 45% slope or more, where bench terraces or natural vegetative cover strips necessary for control of soil erosion are optimally spaced with the least possible reduction of cropping area [Mercado and Laput, 2008]. The farmer should in general be conscious of the fact that yields from components of the intercropping system depend largely on the spacing regime; so that by proper choice of planting arrangement and manipulating component interactions for optimal sharing of growth resources may ultimately lead to increased yield [Francis, 1986].

2.5.2 Maturity Dates

There have been various arguments concerning the mechanisms by which crop mixtures can more effectively use growth resources to give yield advantages at maturity, but the one that appears most significant is the difference in the timing of planting [Trenbath, 1984]. This effect has been shown both for crops differing in time periods to maturity and for similarly maturing crops planted at differing times [Willey 1979]. Planting intercrops that have different maturity dates or development periods takes advantage of variations in peak resource demands for growth factors, so that when one crop matures before its companion crop there is less competition between the two crops during critical growth stages [Lawson and Kang,1990; Nair,1993]. For optimal results, maize is normally harvested when the moisture content (MC) of the dry grain is 14%; but artemisia leaves can be continuously harvested from the plants every 3 to 4 weeks by hand plucking similar to tea picking for a period of 6 months, after which the entire plant can be harvested in total [Ferreira *et al.,* 2005], and air-dried to 8% MC for storage and artemisinin extraction. The optimum time of harvest will depend on the target compound desired and on the variety grown: If artemisinin production is the main objective of an artemisia+maize intercrop, maximum yield in most cases occurs at early bloom to late vegetative stage [Woerdenbag *et al.,* 1994].

2.5.3 Interplant Stand Density

Plant Density is a limiting factor in the conversion of resources into biomass and in this respect, The Law of Constant Final Yield may also have implications for agriculture pertaining to sowing densities [Weiner and Freckleton, 2008] and use of fertilizers, in that regardless of high levels of nutrient application, there will be an upper limit of biomass that can be produced in mixed-species stands or multi-functional agroforestry. The "Niche Differentiation" process also allows two intercrop species to partition certain resources so that one component does not out-compete the other as dictated by the competitive exclusion principle [Tilman, 1990]. Furthermore, the average per-capita landholding in western Kenya will continue to decrease in size with increased demographic pressure, and hence there is a limit to the wide application of improved fallows [Swinkels *et al.,* 1997] or monoculture maize production with commercial fertilizer application. In order to optimize plant density in any intercropping system, the seeding rate of each crop in the mixture should thus be adjusted to below its recommended full rate [Sullivan, 2003] without necessarily increasing rate of fertilizer application.

In this study, seed rate for artemisia refers to transplanted seedling density while for maize it is the virtual number of seeds per hole. Artemisia seeds are so minute that propagation of the plant is conveniently done from cuttings through vegetative propagation techniques, with the added advantage of maintaining genetic qualities in the plant [Ferreira *et al.*, 2005]. According to Owuor [1999], establishment of such tiny seed by direct sowing is feasible only with a mixture of fine sand or soil in a shallow seedbed and done during times of ample rainfall. On the other hand, propagation of maize is done from pre-treated seed and if the full recommended rates of both intercrops were planted; neither would produce optimal yields due to overcrowding [Sullivan, 2003]. By scaling down the seeding rates of each, both crops can therefore yield well within the mixture. In cases where a longer vegetative phase is desirable, intercropping at higher density was reported for indigenous African vegetables [Maritim, 2006.]. According to Fukai and Trenbath [1993], AF 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, and interactions between intercrop components vis-a-vis plant density [Fukai and Trenbath, 1993]. Consequently, when designing suitable plant architecture or spatial arrangements for such intercrops as maize+artemisia, close attention to detail with regard to plant morphological characteristics and competitive abilities or limitations may be critical for desirable component interactions for expected biomass and yields.

2.6 Parameters for Component Interactions

Willey [1985], states that there are two distinct parameters that should be recognized in the evaluation of intercropping advantages: 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 intricacies may therefore need a thorough understanding before development of an intercropping system for recommendation [Mouneke *et al.,* 1997], since a biologically efficient system may not necessarily be economically viable [Ghulam *et al.*,2003]. The potential benefits or loss of any intercropping system can be due to increased yields, decreased input costs or a combination of both. This complementarity between species leads to niche differentiation, which may form the basis for targeting competition for growth resources and maximizing yields in intercropping systems.

Several concepts and/or indices have hence been employed over the years by diverse scholars to evaluate component interactions for competition and potential benefits, losses or efficiency of various intercropping systems: Relative crowding coefficient, RCE [De Wit, 1960]; Coefficient of aggressivity, CA [Mc Gilchrist,1965]; land equivalent ratio, LER [Willey, 1979]; Competitive ratio, CR [Willey and Rao, 1980]; Niche differentiation index, NDI[Spitters, 1983]; Cost-Benefit Analysis [Jaetzold and Schmidt, 1983]; Area x time equivalent ratio, ATER [Hiebsch and McCollum, 1987]; Relative Value Total, RVT [Vandermeer, 1989]; Replacement value of intercropping, RVI [Van der Meer ,1989]; Alley Farming Index, AFI [Blair,1998]; Radiation use efficiency, RUE [Schnieders, 1999]; Light extinction coefficient, *k*df [Baumann *et al*., 2002]; and Monetary Advantage Index, MAI [Ghosh, 2004] among several others. These indices variously measure interspecies competition, facilitation and/or productivity of the respective systems by comparing yields and economic gains in intercropping with that of the monocrop. However, since each of the indices has its own peculiar limitations and is generally applied according to specific experimental objectives, Van der Meer [1989] suggested that whichever concept is adopted must be well understood by the researcher and/or farmer to the extent of guiding on the allocation of limited or available resources between competing demands.

2.6.1 Land Equivalent Ratios (LER)

The LER is a measure of biological yield advantage commonly used to evaluate the efficiency of intercropping systems in optimizing land use as compared with monocrop yields [Gosh, 2004]. The LER was slightly modified and effectively used by Rao and Coe, [1992] in evaluating productivity from Agroforestry systems incorporating shrubs. A LER of more than unit value indicates an advantage to intercropping over monocropping on basis of land use where plant density varies. For example, a LER value of 1.3 would indicate that 30% more land would be needed to produce a given amount of either of the two crop components in pure stands as in mixtures. A contrasting measurement is the Relative Yield Total (RYT), by Van der Meer [1989] where total plant density in the system is kept constant but proportions of crop components vary [Bauman *et al.,* 2002]. The LER also measures the level of intercrop interference going on in the cropping system [Mazaheri *et al.,* 2006] to the extent that if the agro ecological characteristics of each crop in a dual mixture are exactly the same, the total LER should be 1.0 and the partial LERs should be 0.5 for each. The LER index assumes that the proportion of components to be harvested from the intercrop is the ideal or required proportion, and this may constitute an inherent limitation: Higher LER values occasioned by depressed monocrop yields may be misleading since LER is based on yield ratios of crops and is sensitive to the monocrop yields in that the lower the monocrop yield the higher the LER value [Francis, 1986]. Much work has been done on maize+bean intercropping systems [Gardner and Kisakye, 1990; Odhiambo and Ariga 2001; Macharia and Shiluli, 2003; Woomer *et al.,* 2004] but the yield advantage of maize+beans over artemisia+maize intercropping systems using LER has not been documented. Best LER indices have however been obtained in a spatial arrangement of one row of double seeded maize to two [Woomer, 2004] or three rows of beans.

2.6.2 Area x Time Equivalent Ratios (ATER)

Yield advantages in intercropping systems may be attributable to differential use of growth resources by the component crops and according to Willey and Reddy [1981], in order for significant complimentarity to occur in an intercrop situation, the growth pattern of component crops should vary with time. Assuming that there could be a certain threshold duration of time within which crop residues from a previous harvest is still beneficial to a subsequent intercrop stand, the "Effective LER" or Area-time Equivalent Ratio (ATER) values of a second and subsequent cropping seasons could be ideal for evaluating intercrops in both spatial and temporal arrangement of time [Hiebsch and McCollum, 1987]. This resolves the interpretive inadequacy of LER by including duration of land occupancy [Hiebsch, 1980] in the intercrop versus monoculture comparisons. The ATER may thus present a superior biological approach to LER for comparing annual productivities of intercropping systems over time, that presumably include short fallow periods; but the problem is that both calculations do not account for the value of the crops that are being grown [Moseley, 1994; Ghulam *et al.*,2003].

2.6.3 Competitive Ratio

Measurement of inta- and intra-plant competition in AF intercropping systems are conventionally evaluated on basis of weather the crop mixtures are in *Additive* or *Replacement* series [Fukai and Trenbath,1993]. Relative Crowding Coefficient (RCC) first documented by De Wit, [1960] and modified by Willey and Rao [1980] measures competitive ability of crop species in a mixture assuming that the mixture treatments form a replacement series. Spitters, [1983] also proposed the Niche Differentiation Index (NDI) to quantify the competitive ability of each species for a given resource when the two crop species are in mixed culture. The NDI also captures the level of intra specific and interspecific competition in two intercrops. After appreciating that yield advantages in intercropping system are often associated with the fuller use of environmental resources over time by competing component crops, Willey and Rao [1980] suggested a simple competitive ratio (CR) as a measure of intercrop competition or relative species competition to indicate the number of times by which one component crop is more competitive than the other. Competition may not always result in a poor performance of the intercrop since, 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 thus be more applicable interchangeably in 'Additive Series' of intercropping with the NDI that is more suitable in 'Replacement Series' of intercropping targeting interplant competition for one specific growth resource.

2.6.4 Cost-Benefit Analysis

The overriding concerns of small-scale farmers in western Kenya is more with sustaining the farm family in terms of food security rather than with production for profit [Jaetzold and Schmidt, 1983]. These farmers account for 75% of Kenya's total maize production [Mwololo, 2010] but compared to several other farm enterprises, maize is relatively less profitable as a monoculture thereby making it a low value commodity [Nyoro, 2002]. This may be attributable to the fact that small-scale maize farming systems depend on family labour for key operations thus incurring higher intrinsic costs. Cost Benefit Analysis (CBA) may hence provide a basic tool to inform and evaluate the economic yield advantages of a range of intercropping alternatives especially for small farm-scale productivity. The production expenses or variable costs include labour and non-labour expenses. Non-labour expenses include the costs of inputs such as seeds or seedlings and fertilisers, transport and gunny bags for storage, all costed at the prevailing market rates. Land as a raw material in production is normally assumed to be a fixed input because it does not change in the short term [Makeham and Malcolm, 1986] and is therefore rarely costed. Labour costs include the activities carried out by a farm family or hired labour for land preparation, planting, weeding, fertilizer applications and harvesting of the intercrops. All farm activities yield the number of man days used to carry them out; and by multiplying the number of man days with the local labour wage rate, the costs of the activity for each intercropping system is determined [Alabi and Esobhawan, 2006].

2.6.5 Replacement Value of Agroforestry

The replacement value of intercropping (RVI) by Van der Meer [1989], could be modified to better interpret agroforestry improvements with fallow farming systems, and hereby referred to as Replacement Value of Agroforestry [Moseley, 1994]. The modified index captures some of the limitations associated with LER by accounting for crop duration and the relative economic advantage of an AF intercropping system that includes variable costs in the production process. The equation provides an improved estimate of the relative advantage of an intercropping system employing short fallow periods; and a measure of the proportion of time that a field is actually in production over the medium to long term period. In case the fallow period is less than unit value (i.e. one year) for either the monoculture or polyculture situation, then the RVA will yield the same result as the RVI [Moseley, 1994]. From available literature there seems to be little variation between AFI [Blair, 1998] and RVA [Moseley, 1994]. The RVA may currently be superior to the other intercropping indices for evaluating biological yield advantages in AF intercropping experiments because they also accounts for the time in years and variable costs in the production process [Alabi and Esobhawan, 2006].

CHAPTER THREE: MATERIALS AND METHODS

3.1 Site characteristics

The experiment was carried out at Maseno University field station, UM_3 – which is a seasonal semi-deciduous moist Agroforest climate [FAO, 1978]. Maseno area lies at latitude 00° 01'N – 12'S and longitude 34°25'E-47'E. The altitude at the experimental site is 1500m above sea level.; Latitude 00' 08''S and Longitude 34^0 35' 47''E; The experimental site receives a mean annual precipitation of 1750 mm with a bimodal distribution and mean diurnal temperatures of 28.7 deg.C. With this close proximity to the equator, it means day-length variation at the site is not significant. 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 4.6 and 5.4, and are deficient of P and N, with a moderate fixation of P [Jaetzold *et al.,* 2005]. Soil organic carbon and P contents at Maseno are 1.8% and 4.5mg Kg^{-1} respectively [Okalebo *et al.,* 1999]. On the easterly side of the experimental site, there is a hedge of tall *Eucalyptus spp* trees which serve as a wind break.

3.2 Experimental Design and Treatments

3.2.1 Layout

The experiment was carried out during the period from September 2009 to August 2010, relying on rainfall precipitation of two consecutive seasons interspersed with a fallow period of 45 days. The experiment had nine treatments, laid out as a randomized complete block design (RCBD) in 3 replicates, with three different intrarow spacings of the artemisia i.e. 0.75m, 0.9m, and 1m respectively, and uniform displacements of maize from the artemisia at 0.90m X 0.75m in 'Additive series' [Fukai and Trenbath, 1993]. The plant architecture and spatial arrangements were designed to allow for artemisia crown development and minimise adverse component interactions like shading effect or competition from either crop component, while allowing for a 1m width foot path between plots. The overall density was thus higher in the intercrop than in the sole crop and conforming to local practice of maize cultivation in optimal use of small land sizes. Two maize seeds per hill were sown and later thinned to one plant 15 days post emergence. Each trial plot size measured 6m x 4m. Two control plots of pure stands for each crop were established and spaced at 0.75m x 0.90m for maize and 1m x 1m for artemisia respectively. Another plot of maize-beans intercrop was also established for comparative LER analysis, using 0.25m interow spacing and 0.1m within rows so as to allow two rows of beans between the maize rows [Woomer, 2004] to mimic the conventional farm practice in agricultural landscapes of western Kenya. All the blocks were laid out adjacent to each other on a site of land with a slope of 6-9%, whereby a 90m long trench of width 0.20m and depth of 0.5m was dug out on the eastern lower boundary, draining into a permanent furrow perpendicularly facing an adjacent field so as to mitigate potential run-off into the experimental plot. With due regard to AF experimental objectives [Coe, 2002], the treatments were designed as follows:

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);*
T_9 = *Maize 0.90m X 0.75m + 0.25 m Beans line displacements of two rows.*

3.2.2 Crop management practices

The experimental plot was designed to drain in an east- west direction in tandem with the topography of the wider farm. Land was prepared to fine tilth before planting of certified maize seed from Kenya Seed Company of variety H_{513} in short rains and H_{515} in long rains both of which mature in 100 to 150 days, with similar yield potential and recommended for medium altitude AEZ with bimodal rainfall patterns. The option of using the two varieties was necessitated by availability in the market at the time of carrying out the experiment. The F_1 artemisia seedlings were sourced from the East African Botanicals Company Limited (EABL) contracted nursery at Soy - Eldoret where they are raised annually in trays under light shade of 60%. The seedlings were transported in polytubes to the Maseno experimental site one month before transplanting to secure uniform heights (*see* plate 1); and clustered in a temporary open air nursery with adequate moisturisation so as to acclimatize and minimize transplantation shocks during planting.

The first season (SR) maize was planted on 27th September 2009, while the second season (LR) maize was planted on 15th April, 2010. The 1st weeding of maize took place at knee high length in both seasons, after which transplanting of the artemisia crop was done within a span of one week in both the SR and LR seasons respectively, when the young plants had grown to 50 cm in height with average of 15 true leaves, in accordance with the general practices of Ferreira *et al.*, [2005]. The transplanting of artemisia during both the two seasons took place after the rains had soaked the ground sufficiently (October, 2009 and April, 2010 respectively) to ensure the soil has high moisture content to promote seedling vigour. Holes were dug in the wet ground deep enough to hold all the artemisia roots vertically at the base so as to minimise bends on the roots, and forestall developing a poor root system that provide risk of failing plants.

Diamonium phosphate (DAP) fertilizer was applied at planting of maize in all the plots at the recommended rate of 50 kg ha^{-1} while Calcium ammonium nitrate (CAN) was used for localized top dressing of maize (*see* plate 2) only after 1st weeding at the rate of 50 kg ha^{-1}. The second season (LR) land preparation incorporated into the soil previous root stumps from the intercrop according to the practices of Okalebo *et al.,* [1999] and Laughlin [1994] for maize and artemisia respectively. The second weeding in both seasons was done by manually uprooting the few weeds that emerged so as to effect minimal disturbance on soil structure.

A shortened fallow period of 45 days was employed in between the two growing seasons, SR and LR using the same plot and layout, after which the duration was factored in determining the Area-time Equivalent ratio according to the method of Hiebsch and McCollum [1987]. After extrapolation, plant densities from this artemisia+maize intercrop ranged from 10000, 11667, 14583, 16667 plants ha^{-1}for artemisia and 20833 plants ha^{-1}for maize respectively. All other agronomic practices that include harvesting and post-harvest handling were done as currently practiced for artemisia production [WHO, 2003; EABL, 2005] and maize [Wasonga *et al.,* 2008].

All plants were monitored weekly throughout the growing seasons for signs of pest infestation or disease incidence, and data taken on general plant development. Type and relative incidence of weeds were taken on monthly basis. Harvesting of artemisia in both seasons was done when the plants started showing signs of bud initiation. 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. Maize was harvested and shelled manually afterwhich fresh weights and dry weights measured for biomass after drying to mimic farmers' practice. In order to conform to good agricultural practices for medicinal plants [WHO, 2003] as much as possible, there was no usage of pesticides in control of pests and diseases. Rainfall or precipitation was collected using the Nylex "1000" Professional

Rain Gauge based at Maseno Veterinary farm on monthly basis during the duration of the experiment.

3.3. Data Collection

Five plants from each test plot with guard rows were selected randomly and tagged for consistent recording of the various growth patterns and yield attributes.

3.3.1 Plant growth parameters

The averages of five individual plants per plot were used for growth measurements of both maize and artemisia in each treatment using a standard 2-meter rule. Plant height was measured from the stem base to shoot apex for all sample plants from date of emergence and subsequent measurements taken after every 4 weeks. Similarly, crown diameters for artemisia were measured from the branch internodes of the longest branches (plate 4) after attaining physiological maturity. This parameter was restricted to artemisia only, unlike maize which lost turgidity at the same period. Days to maturity of all intercrops was determined by counting the days from date of emergence to plant physiological maturity.

3.3.2 Plant biomass

Above ground plant biomass of both maize and artemisia was determined at harvest using farmers' practice. Artemisia above ground shoot per hill was severed at the root apex and the harvested plants placed in brown paper bags after sun drying, after which they were weighed using an electronic weighing balance (Denver instrument model XL -31000) at Maseno Botanical garden. A similar treatment was also done for maize in which measurement was done with dry whole stalks severed at the root apex.

3.3.3 Chlorophyll content determination

Evaluation of the plants' relative nutritional status in the immediate pre-harvest period was done by non-destructive measurement of chlorophyll content of the leaves using a

SPAD-502 meter (Plate 4), three times each season within a weeks' interval for both season's crops. Triplicate readings (SPAD Units) were taken around the midrib of each sample leaf according to the method of Peng *et al.*, [1992], within 15cm of shoot apex and averaged per plant. The last SPAD reading for artemisia was done at flowering while for maize it was at physiological maturity. These readings were taken to coincide with periods of optimal vegetative growth for the intercrops and their respective pure stands, according to Woerdenbag *et. al.*,[1994].

3.3.4 Artemisinin content determination

The artemisia plants were threshed whole and ensuing leaves air dried on black polythene sheets to 8% moisture content determined by moisture meter, after which a representative sample from each treatment was forwarded to laboratory for bioassay. The extraction and analysis of artemisinin from the artemisia leaves was done at EABL factory in Athi River, following the method of Christen and Veuthey [2001]. This method entails grinding dry artemisia leaf to powder followed by extraction and analysis of artemisinin content using HPLC with Mass Spectroscopy (MS) in the laboratory. A correlation analysis between chlorophyll (x) and artemisinin (y) content of artemisia treatments only (n=7) at harvest time for artemisia was done using Pearson's Correlation Coefficient (r):-

$$r = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{n(\sum x^2) - (\sum x)^2}\sqrt{n(\sum y^2) - (\sum y)^2}}$$

3.3.5 Yield components and Yield

The yield components and yield for all intercrops was derived from an area of $24m^2$ per plot and extrapolated into production per hectare where applicable. Yield of maize grain at 14% 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.

3.4 Determination of Yield Advantage from Derived Parameters

The determination of yield advantages if any and competitive interactions were done using the following six selected indices:-

3.4.1 Land Equivalent Ratios (LER)

Partial LER was determined by dividing yields for artemisia shrubs, maize and beans by their respective mono crop yields and the resulting ratios (relative yields) added to obtain the total LER values according to the method of Willey [1979] as modified by Rao and Coe, [1992]:-

$$\text{LER} = C_i/C_s + T_i/T_s \qquad (1)$$

Where, C_i = crop yield under intercropping

C_s = crop yield under sole cropping

T_i = Shrub yield under intercropping

T_s= Shrub yield under sole system.

Values of LER>1 were considered advantageous. For purposes of this study, LER for maize+beans and maize+artemisia respectively was derived from the maize and bean grain yields in Kg ha^{-1}; and dry biomass yields of artemisia leaves ha^{-1} from treatments recording a minimum artemisinin content of 0.7%.

3.4.2 Area x Time Equivalent Ratio (ATER)

The ATER value per treatment was a summation of partial ATER values from the LR season only. ATER for each treatment was determined by multiplying the relative yield by the ratio of the time (days) taken by the crop to maturity when grown in monoculture, to the total time taken including fallow period by all components under intercropping using the method of Hiebsch, [1980] as modified by Hiebsch and McCollum[1987]. The total duration of the intercrop system used was 300 calender days i.e. Sum of 105days for maize, 150days for artemisia and 45 days fallow period between SR and LR seasons. Substituting for artemisia+maize per treatment in the LR season, the equation of [Hiebsch, 1980] was used for Artemisia +Maize and Maize + Beans per treatment, according the method of Hiebsch and McCollum, [1987]:

$$\text{ATER} = \sum_{i=1}^{n} \frac{t_i^S}{t_I}\left(Y_i^I / Y_i^S\right) \qquad \textbf{(2)}$$

Where, Y_i^I and Y_i^S are the yield of crop I in intercropping and sole cropping, respectively and n is the total number of crops in the intercropping system; t_i^S is the growing period of crop I in sole cropping and t_I is the total duration for the intercropping system including fallow period.

3.4.3 The Competitive Ratio (CR)

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] as modified by Willey [1985] to account for the practical objective of determining mutual intercropping advantages. Substituting for artemisia and maize intercrop, the CR index was calculated using the following formula:

$$\mathbf{CR_{maize} = (LER_{Maize} / LER_{Artemisia}) \times (Za / Zm),} \qquad \textbf{(3a)}$$

$$\mathbf{CR_{Artemisia} = (LER_{Artemisia} / LER_{Maize}) \times (Zm / Za)} \qquad \textbf{(3b)}$$

Where, LER_{Maize} is the partial LER for maize, $LER_{Artemisia}$ is the partial LER for artemisia. Zm and Za are the proportions of maize and artemisia in the mixture respectively.

3.4.4 Replacement Value of Intercropping (RVI)

As a measure of relative economic yield advantage of intercropping artemisia and maize, RVI was determined for each treatment following the method of Van der Meer [1989] as modified by Moseley [1994] to incorporate a fallow period of less than unit value (one year); as well as variable costs that account for labour and farm input used in the production process of the AF system. Substituting for artemisia and maize intercrop interchangeably [Moseley, 1994]:

$$RVI_{Artemisia} = (a \times Y_{Artemisia} + b \times Y_{Maize}) / a \times MY_{Artemisia} - C \qquad \textbf{(4a)}$$

$$RVI_{Maize} = (a \times Y_{Maize} + b \times Y_{Artemisia}) / a \times MY_{Maize} - C \qquad \textbf{(4b)}$$

Where:

$Y_{Artemisia}$ and Y_{Maize} are the yields of Artemisia and Maize in the mixture respectively.

$MY_{Artemisia}$ is the mono crop yields of Artemisia to be used interchangeably with MY_{Maize} for Maize monocrops; ***a*** and ***b*** are the market prices of artemisia and Maize respectively; **C** is the variable cost associated with mono-cropping artemisia or maize interchangeably for replacement i.e. labour costs, cost of planting material and fertilizer.

3.4.5 Cost-Benefit Analysis (CBA)

Cost-benefit analysis (CBA) was done according to the prescription of Jaetzold and Schmidt, [1983] and Makeham and Malcolm, [1986]: 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), maize (Ksh 2500 per 90kg bag) and beans (Ksh 4500) was used for analysis of monetary benefits.

Mono-culture yields per plot and market prices of both artemisia and maize were recorded at harvest while the respective total variable costs associated with mono-cropping i.e. cost of planting material, fertilizer and labour for the two seasons were also recorded and periodically updated. The costs and amount of hours spent on bush clearing, planting, weeding, fertilizer application and harvesting were recorded on per plot and 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 per MD:-

$$MD=H/T \qquad (5)$$

Where H is the cumulative hours of labour input and T is time of standard 8 hour working period. All other costs were computed from each treatment on the basis of prevailing market price of fertiliser, artemisia leaf yield, and maize and bean grains. The economic analysis was performed on cumulated costs and benefits over the 2 cropping seasons SR and LR. All costs were extrapolated into Kenya shillings (K*s*h) per Ha. for each treatment. Net benefits were expressed as the difference between the total benefit and the gross variable costs per treatment. 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 and beans or in monocultures.

3.4.6 Land Use Efficiency (%LUE)

The % LUE for each treatment was calculated by averaging the sum of LER and ATER respectively [Rao, 2002], indicating which cropping pattern was more efficient in the use of land, area and time for optimal yield:

$$LUE = (LER + ATER)/2 \qquad (6)$$

Where, LER is the partial land equivalent ratio for either intercrop in a season and ATER is the Area-Time Equivalent ratio as defined in **(1)** and **(2)** respectively above.

3.5 Statistical Analysis

Data was subjected to analysis of variance (ANOVA) using the Costat statistical computer package. The treatment and block means were separated using the least significant differences (LSD) test at 5%, while homogeneity of variances was verified by Bartlett's test [Sokal and Rohlf,1995].

CHAPTER FOUR: RESULTS

4.1 General Observation

The rainfall pattern in the two seasons (Fig 4.1) in which the experiment was carried out indicates that distribution pattern was relatively similar but there were more rains in the long rain (LR) than in the short rain (SR) season by a factor of 1.5; The amount of precipitation during SR was more than double that of LR at critical stages of bud initiation for artemisia, during the months of December and July respectively. No pests or diseases affected the intercrops throughout the two growing seasons except a few cobs of maize with head smuts *Ustilago maydis* observed in T_9 during the LR season. The maize+bean intercrop had a more pronounced incidence of weed infestation including Black Jack (*Bidens pilosa*), *Oxalis latifolia*, Wondering Jew (*Commelina bengalensis*), *Cynodon dactylon*, and *Chloris gayana*, unlike all the maize+artemisia intercrops (plate 3) which had none after the first weeding and canopy closure of artemisia. This had a net effect of reducing labour costs of weeding in artemisia pure stands (Table 4.5). The LR artemisia crop flowered earlier than the SR crop by 20 days.

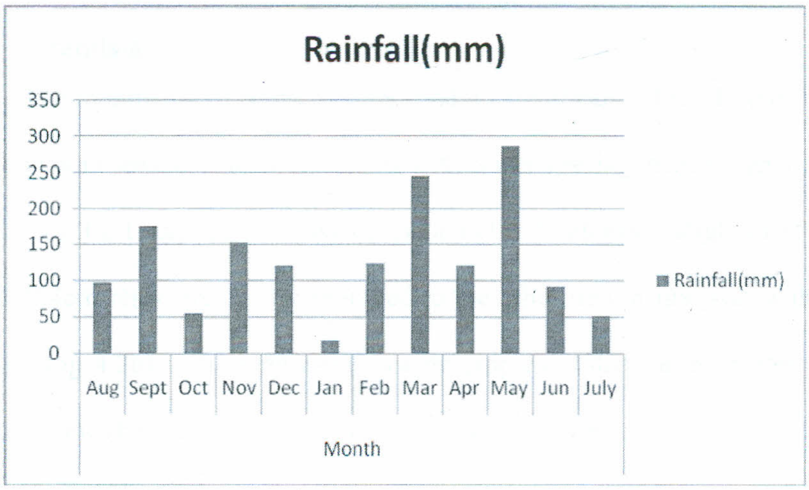

Fig 4.1 : Rainfall Pattern Maseno Area (Aug 2009 – July 2010). Source: Maseno Agricultural Training Centre.

4.2 Plant Heights

4.2.1 Maize

The treatments had no significant effect ($P>0.05$) on plant height of maize during both seasons (Fig.4.2a). The long rains' (LR) season crop exhibited mean taller plant heights of 158cm than the short rains (SR) season crop with 128cm at physiological maturity.

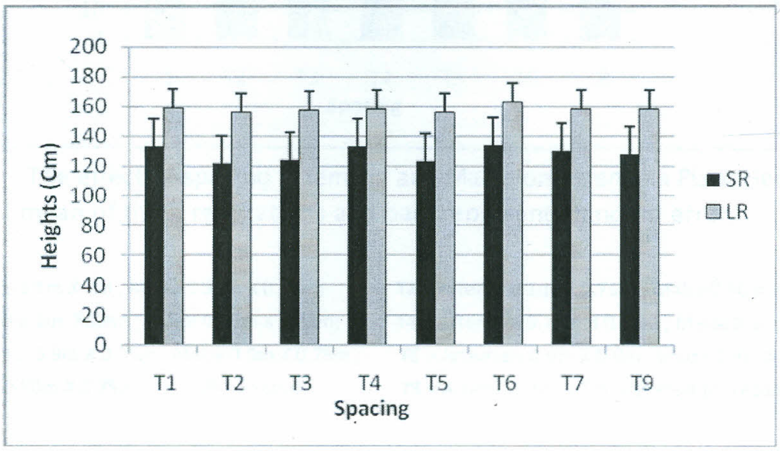

Fig. 4.2a: The effect of spacing Artemisia and Maize on Maize Plant Heights. Data points are the mean of three replications and bars represent standard errors.

+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 Maize (Pure Stand) **T8** = Artemisia 1m X 1m Artemisia (Pure Stand)
T9 = 0.90m X 0.75m Maize, 0.25 m Beans line displacements of two rows.

4.2.2 Artemisia

The treatments (spacing regimes) had no significant effect ($P>0.05$) on artemisia plant height in both seasons. However, plants with closer spacing, hence higher intercropping densities i.e. T_4, T_5, T_6 and T_8 (pure stand) had a higher mean plant height of 158cm, 154cm, 152cm and 154cm respectively, as compared to the other treatments with wider spacing at harvest time (Fig 4.2b). The long rains' season crop exhibited mean shorter plant heights (120.1cm) than the short rains season crop (177.4cm) at harvest.

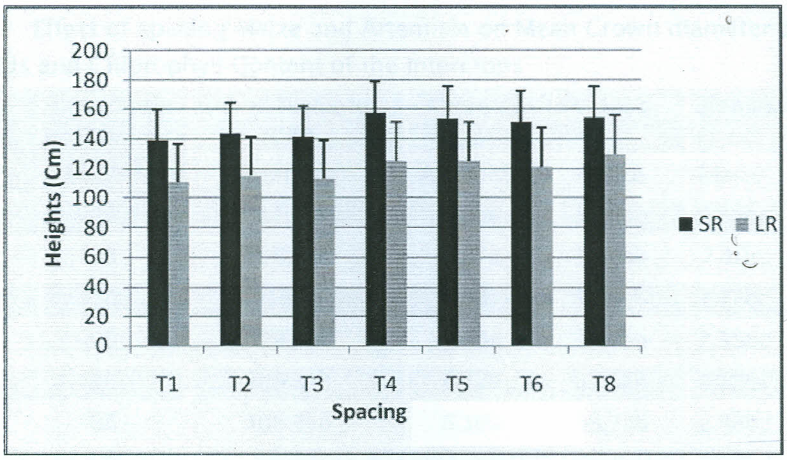

Fig. 4.2b: The effect of spacing Artemisia and Maize on Artemisia Plant Heights. Data points are the mean of three replications and bars represent standard error.

$^{+}$**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 Maize (Pure Stand)
T8 = Artemisia 1m X 1m Artemisia (Pure Stand)

4.2.3 Crown Diameters

Spacing had no significant effect (P>0.05) on artemisia crown diameters but T_3 recorded a high value at 116.8 that was significantly different from T_4 at 99.9 (Table 4.1).

4.3 Plant Biomass

4.3.1 Maize

The treatments had a significant effect on plant biomass of maize ($P < 0.05$). Apart from the pure stand of T_7 at 3.85t ha^{-1}, T_3 recorded the highest values at 2.78t ha^{-1} that was not statistically different from other treatments; maize T_2 recorded the lowest biomass yields at 2.1tha^{-1} and was statistically different from T_7(Table 4.1).

Table 4.1: Effect of spacing Maize and Artemisia on Mean Crown diameter of Artemisia, Biomass Yields and Chlorophyll Content of the Intercrops

Spacing+	Intercrop Population (24m^2)	Crown Diameter (Cm)	Chlorophyll Content (SPAD Units)		Biomass yields(t/ha)	
		Artemisia	Artemisia	Maize	Maize	Artemisia
T1	85	111.3ab	5.95a	35.5ab	2.38bc	7.36bc
T2	78	108.7ab	6.67a	37.9ab	2.10c	7.29bc
T3	74	116.8a	5.98a	37.6ab	2.78bc	5.39d
T4	90	99.9b	6.30a	37.7ab	2.35bc	9.67a
T5	90	106.7ab	6.12a	37.5ab	2.25bc	8.975a
T6	85	108.2ab	6.10a	38.7ab	2.38bc	7.08c
T7	50	-	-	39.1a	3.85a	-
T8	35	108.4ab	6.65a	-	-	8.75ab
T9	195	-	-	25.7b	2.28bc	-
CV%	-	11.8	14.8	7.38	19.96	16.45
LSD0.05	-	22.7	1.1	4.3	0.31	0.81
Significance	-	ns	ns	ns	*	*

{Mean values in a column followed by dissimilar letter(s) indicate differences at 0.05 (*) level of significance. ns =Not significant at P>0.05}

$^{+}$**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 Artemisia (Pure Stand)

T9 = 0.90m X 0.75m Maize, 0.25 m Beans line displacements of two rows.

4.3.2 Artemisia

Spacing had a significant effect on plant biomass of artemisia (P>0.05) but T$_5$ (8.98t ha^{-1}), T$_4$ (9.67t ha^{-1}) and T$_6$ (7.08t ha^{-1}) were not statistically different from each other (Table 4.1) and recorded the highest values for artemisia respectively apart from the pure stand of T$_8$ (8.75t ha^{-1}). Artemisia T$_3$ had the least value at 5.39t ha^{-1} and was statistically different from the rest (Table 4.1).

4.4 Chlorophyll Content

4.4.1 Maize

There was no significant effect (P>0.05) of spacing on relative Chlorophyll content of maize at harvest during both SR and LR seasons but T_7 at 39.1 recorded a higher value than T_9 at 25.7 (Table 4.1)

4.4.2 Artemisia

There was no significant effect (P>0.05) of spacing on relative chlorophyll content of artemisia at harvest (Table 4.1). Chlorophyll content had a positive correlation (r^2 = 0.7) with artemisinin content at harvest (Fig. 4.4) and Table 4.2

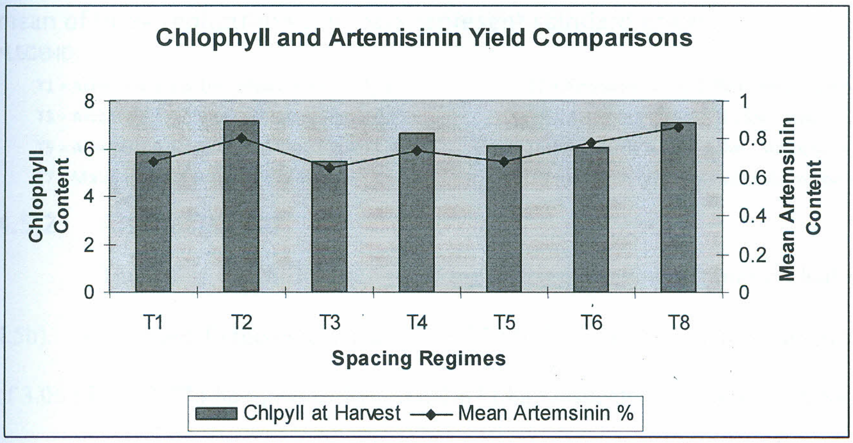

Fig. 4.4: Chlorophyll content and Artemisia Yield Comparison; R^2 = 0.7 Data points are the mean of three replications

$^+$**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
T8 = Artemisia 1m X 1m (Pure Stand)

4.5 Intercropping Yields

4.5.1 Maize Grain

There was a significant effect (P>0.05) of spacing on grain yields in both the SR and LR seasons (Fig.4.5a). During the LR, T_1 and T_6 recorded the highest values of 3.251t h^{-1} and 3.02t h^{-1} respectively that were significantly different from T_2 (2.85t h^{-1}), T_3 (2.7t h^{-1}), T_4 (2.7t h^{-1}) and T_5 (2.7t h^{-1}). In the SR, T_1 (3.12t h^{-1}) and T_2 (2.86t h^{-1}) recorded the highest yields but not significantly different from all treatments except the pure stand T_7 with 3.84t h^{-1}. T_9 recorded the highest values in both seasons i.e. 4.7t h^{-1} and 4.3t h^{-1}, for SR and LR respectively.

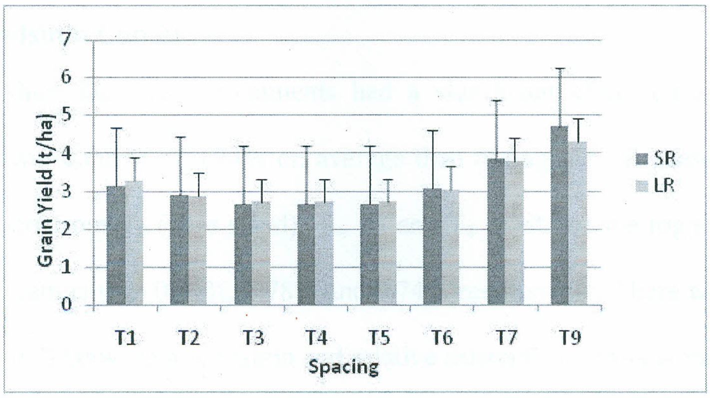

Fig. 4.5a: The effect of spacing Artemisia and Maize on Maize Grain Yield. Data points are the mean of three replications and bars represent standard errors.

+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)
T9 = 0.90m X 0.75m Maize+ 0.25 m Beans line of two rows.

4.5.2 Artemisia Leaf

There was a significant effect of the different spacing regimes on leaf yields (P>0.05) (Fig. 4.5b). Apart from T_8 the pure stand with 3.77 t ha^{-1}, T_3, T_5,T_4 and T_6 returned the highest leaf yield of 3.06 t ha^{-1} , 2.77 t ha^{-1} , 2.42 t ha^{-1} and 2.67 t ha^{-1} respectively and were statistically different from T_1 with the lowest yield at 1.56 t ha^{-1} during the short rains.

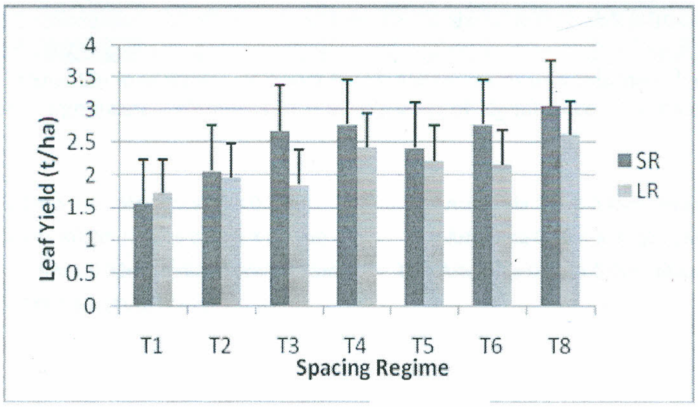

Fig. 4.5b: The effect of spacing Artemisia and Maize on Artemisia Leaf Yield. Data points are the mean of three replications and bars represent standard errors. Legend as in Fig.4.5a above; **T8** = Artemisia 1m X 1m (Pure Stand)

A similar trend was observed during the long rains where T_4 recorded the highest value at 2.42 t ha^{-1} and was statistically different from T_1 the lowest with 1.73 t ha

4.5.3 Artemisinin Content

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 4.2). 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 harvest (Table 4.2).

Table 4.2: Effect of Spacing Artemisia and Maize on % Artemisinin Content (Art.)

Treatment+	Art.LR	Art.SR (Y)	Chl (X)	X*Y	X2	Y2
T1	0.76ab	0.65b	5.95	3.87	35.40	0.422
T2	0.83a	0.74ab	6.67	4.94	44.49	0.547
T3	0.76ab	0.78a	5.98	4.66	35.76	0.608
T4	0.84a	0.81a	6.30	5.04	39.69	0.640
T5	0.71ab	0.68ab	6.12	4.16	37.45	0.462
T6	0.82a	0.68ab	6.10	4.15	37.21	0.462
T8	0.89a	0.86a	6.65	5.72	44.22	0.740
CV %	8.12	7.51	-	-	-	-
Mean	0.80	0.741	6.25	4.65	39.17	0.555
LSD $_{0.05}$	0.13	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	$\sum X^2$=36.11	$\sum Y^2$=0.42
r^2	0.7					

{+see Legend below. LR- long Rains; SR- Short Rains; Mean values in a column followed by dissimilar letter (s) indicate significant differences at 0.05 (*) level of significance; r^2 = Pearson's correlation coefficient}

+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
T8 = Artemisia 1m X 1m (Pure Stand)

4.6 Component Interactions

4.6.1 Competitive Ratios (CR)

Maize

The different spacing regimes had a significant effect ($P<0.05$) on the competitive ratio of maize against artemisia among the intercrops during both seasons (*see* Table 4.2). T_1 was significantly different from other treatments and had the highest CR value for maize at 1.2 while T_3 had the lowest CR value at 0.52.

Table 4.3: Effect of spacing Maize and Artemisia on competitive ratio (CR) of Artemisia and Maize.

Spacing	$CR_{Artemisia}$	CR_{Maize}
T_1	0.85c	1.20a
T_2	1.47b	0.69bc
T_3	1.75a	0.52bd
T_4	1.30b	0.76bc
T_5	1.16b	0.95b
T_6	1.24b	0.80c
T_7	-	0e
T_8	0d	-
CV (%)	19.3	26.49
LSD $_{0.05}$	0.385	0.29
Significance	*	*

{Mean values in a column followed by dissimilar letter (s) indicate differences at 0.05 (*) level of significance. Ns=Not significant at P>0.05}

+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)

Artemisia

The different spacing regimes had a significant effect ($P<0.05$) on the competitive ratio of artemisia against maize among the intercrops during both seasons (Table4.2). T_3 exhibited the highest CR of artemisia against maize at 1.75 while T_1 had the lowest at 0.85.

4.6.2 Land Equivalent Ratios (LER)

The treatments had a significant effect ($P<0.05$) on LER during both seasons (Table 4.4) where T_6 with 1.49 was statistically higher than the pure stands, while T_5 at 1.35 recorded the lowest LER value but was not statistically different from T_6. Mean LER values for maize+artemisia were significantly higher than maize+beans (T_9) at 1.15 in both SR and LR (*see* Table 4.4).

4.6.3 Area-Time Equivalent Ratios (ATER)

The treatments had a significant effect on ATER ($P<0.05$). Since ATER was derived from the long rains LER, the ATER values followed a trend similar to that of LER (*see* Table 4.4). The total ATER for all the treatments showed T_4 and T_6 with the highest at 1.0 each followed by T_3 (0.95) and T_2 (0.9). T_4, T_5 and T_6 were statistically different from T_1 (0.8), T_7 (pure maize at 0.35) and T_8 (pure artemisia at 0.5); the highest partial ATER of 0.5 was recorded from the pure stand of T_8 and as was the case with LER, T_1 at 0.8 recorded the lowest ATER value. The mean ATER value for maize+artemisia at 0.86 was significantly higher than maize+beans (T_9) at 0.5 while ATER values for maize+beans (T_9) were significantly higher than the pure stand of maize (T_7) at 0.35.

4.6.4 Replacement Value of Intercropping (RVI)

Maize

There was no significant effect of spacing on RVI ($P>0.05$) during both SR and LR seasons but season had a significant effect ($P<0.05$) on the treatments (Table 4.4).

Artemisia

There was a significant effect of spacing on RVI ($P<0.05$) during both SR and LR seasons (Table 4.4). T_6 recorded the highest RVI value at 1.6 and was statistically different from T_1 (1.3) but not different statistically from treatments T_2, (1.4) T_3, (1.4) and T_4, T_5 that recorded a RVI of 1.5 each. The lowest RVI value was recorded from T_7 the control with 1.1 and was statistically different from all other treatments. In general, the results of biological yield advantage using RVI, LER and its derived parameters indicated that T_3, T_4, T_5, and T_6 were not statistically different from each other (Table 4.4).

Table 4.4. Effect of Spacing Maize and Artemisia on Land Equivalent Ratios (LER), Area – Time Equivalent Ratios (ATER) and Replacement Value of Intercropping (RVI)

Spacing$^+$	SR_{LER}	LR_{LER}	$Mean_{LER}$	ATER	$RVI_{Artemisia}$	RVI_{Maize}
T_1	1.23bcd	1.48a	1.36a	0.8bc	1.3bc	1.6a
T_2	1.31abc	1.47a	1.39a	0.9ab	1.4bc	1.5a
T_3	1.34abc	1.30b	1.41a	0.95ab	1.4bc	1.5a
T_4	1.53a	1.49a	1.41a	1a	1.5ab	1.5a
T_5	1.46ab	1.25bc	1.35a	0.9ab	1.5ab	1.5a
T_6	1.55a	1.44a	1.49a	1a	1.6ab	1.7a
T_7	1.00d	1.00d	1.00c	0.35d	-	1.1ab
T_8	1.00d	1.00d	1.00c	0.5c	1.0d	-
T_9	1.16cd	1.14cd	1.15b	0.5c	-	0c
CV (%)	11.3	8.31	6.50	13.08	10.78	21.25
LSD $_{0.05}$	25.15	14.03	14.5	2.66	0.09	0.16
Spacing	*	*	*	*	*	*
Season	ns	ns	ns	ns	ns	*

{Mean values in a column followed by dissimilar letter (s) indicate significant differences at 0.05 (*) level of significance; ns=Not significant at P>0.05}

$^+$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)
T9 = 0.90m X 0.75m Maize, 0.25 m Beans line displacements of two rows.

4.6.5 Cost-Benefit Analysis (CBA).

All treatments were subjected to cost-benefit analysis and yielded maximum values from intercrops T_3 at 82.5 followed by T_5 at 82.2 and T_6 at 80.3 and T_4 at 79.2. The pure stand of T_7 (Maize) recorded very low and high values of 6.45 and 99.5 respectively (Table 4.5). T_1 had the least Gross benefit from artemisia while T_8 recorded the highest at 107.6; in contrast T_1 recorded the highest gross benefit for maize at 7.36 apart from the control of T_7 at 8.76

Table 4.5: Cost benefit analysis (CBA) in *Ksh '000 ha^{-1}

	Spacing*								
Item	T1	T2	T3	T4	T5	T6	T7	T8	T9
Benefits'000/ha									
➢ Maize grain yield	7.36	6.6	6.16	6.16	6.16	6.28	8.76	-	9.56
➢ Artemisia leaf	65.8	80.8	98.6	97.0	100.0	96.8	-	107.6	-
➢ Bean grain yield	-	-	-	-	-	-	-	-	53.04
➢ Total Benefit	73.2	87.4	104.8	103.2	106.2	103.1	8.76	107.6	62.60
Variable Costs'000/ha									
➢ Labour cost	7.80	7.80	7.80	7.80	7.80	7.80	4.2	3.6	8.50
➢ Maize seed cost	4.15	4.15	4.15	4.15	4.15	4.15	4.15	-	4.15
➢ Artemisia seedling	3.85	3.08	2.64	4.4	4.4	3.85	-	3.85	0
➢ Bean seed	-	-	-	-	-	-	-	-	5.63
➢ **Fertilizer costs**	7.70	7.70	7.70	7.70	7.70	7.70	7.70	0	7.7
Total Variable cost	23.5	22.73	22.29	24.05	24.05	23.5	16.05	7.45	25.98
➢ **NetBenefit ('000)**	49.7	64.7	82.5	79.2	82.2	79.6	(7.3)	100.2	36.6

***LEGEND:** {*1USD=K*sh* 85}

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)
T9 = Maize 0.90m X 0.75m + Beans 0.25 m line displacements of two rows.

4.6.6 Land Use Efficiency (% LUE)

Maize

The treatments had a significant effect on land use efficiency ($P<0.05$). T_1 maize obtained the highest LUE value of 56.85% and was statistically different from T_3 (48.3%) and T_4 (47.6%). Significantly, treatments T_1 (56.85%), T_2 (51.4%), T_5 (49%), and T_6 (54.8%) recorded the best indices but were not statistically different from each other (Table 4.6).

Artemisia

The treatments had a significant effect on land use efficiency ($P<0.05$) (*see* Table 4.5). T_3, T_4 and T_6 reported optimum LUE values of 52.8%, 53.2% and 51.5% respectively whereas the same treatments recorded the highest aggregate values for the intercrop at 101.1%, 100.8%, and 106.3%.

Table 4.6: Effect of Spacing Artemisia and Maize on Land Use Efficiency (% LUE)

Spacing+	Artemisia	Maize	Total
T_1	38.5c	56.85c	95.4ab
T_2	47.3b	51.4cd	98.7ab
T_3	52.8b	48.3d	101.1a
T_4	53.2b	47.6d	100.8a
T_5	47.7b	49.0d	96.7ab
T_6	51.5b	54.8cd	106.3a
T_7	-	67.5b	67.5d
T_8	75a	-	75cd
T_9	-	83a	83c
CV	13.5%	12.5%	13.0%
$LSD_{0.05}$	4.48	4.23	4.36
Significance	*	*	*

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

$^+$**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 Maize (Pure Stand)
T8 = Artemisia 1m X 1m Artemisia (Pure Stand)
T9 = Maize 0.90m X 0.75m + Beans 0.25 m line displacements of two rows.

Plate 3: LR artemisia+maize Intercrop T_6, 2 months after transplanting artemisia.

Plate 4: Measuring final plant heights and crown diameters T_2 before harvesting

Plate 5: SR artemisia pure stand T_8 for crown diameters

Plate 6: SR artemisia + maize intercrop T_4 at physiological maturity

CHAPTER FIVE: DISCUSSION

5.1 Effect of Intercropping on plant morphology

5.1.1 Plant heights

Plant height is among the most important morphological attributes of an intercrop. The different spacing regimes tested in this trial had no significant effect on maize plant heights and similar results have been obtained in maize+okra [Oyewole, 2010] and maize+cassava [Olasantan and Lucas, 1996]. Since higher plant heights in intercrops are usually associated with interplant competition for light, 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. Even though the intercrops may have had different growth rates, maize plant heights remained consistently higher than artemisia until physiological maturity, and this may be due to the fact that artemisia was planted sequentially after maize. However, the higher plant heights of maize observed in LR compared to the SR may have been occasioned by higher precipitation levels experienced in LR relative to SR. Similar observations were made by Achieng *et al.,* [2010] who recorded greater plant heights in wetter seasons and reported that besides being a genetic trait maize plant height is also a reflection of nutrient availability, management level and favourable prevailing weather.

There was no significant difference (P>0.05) between treatments with respect to artemisia plant heights at harvest as in maize, and this may have been to due to the fact the spacing regimes tested did not constitute both intra- and inter-species competition for growth resources especially light. The earlier flowering of artemisia during long rains crop compared to the short rains season crop may have been occasioned by change in seasonal micro-environmental factors as an effect of prolonged rain precipitation in LR season

(Fig.4.1) to result in mild water logging at critical stages of bud initiation. This observation is consistent with Marchese *et al.,* [2002] who reported that with regards to flowering, *A. annua* genotypes with similar ecological origins can present variations in their behavior under the same photoperiod and temperature conditions but different levels of precipitation; implying that early flowering could be one of the plants' mechanism of defense against water logging.

In addition, the sequential planting of maize and artemisia plant components on different dates in each season may have individually optimized the use of different agroecological conditions for respective morphological development. Starting with maize, subsequent growth rate of artemisia may not have influenced the established maize crop or provide opportunity for interplant competition for growth factors like radiation. Similar observations from AF experiments have been made by Sobkowiez [2006] while working on Triticale and field beans; Lawson and Kang, [1990] while studying yield of maize and cowpea in an alley cropping system; and Gathumbi *et al*., [2004] on the general effects of species interaction on growth and productivity of intercropping, all of who postulate that planting intercrops that have different development periods due to sequential planting takes advantage of variations in peak resource demands for growth factors, so that when one crop matures before its companion crop there is less competition between the two crops during critical growth stages. The wider implication of results from this trial is that by staggering the planting dates, maize+artemisia intercrops can be most productive when each component crop differs in growth rate, so that presumably their individual optimal requirements for growth resources occur at different times.

5.1.2 Crown Diameters

Plants in either monocrops or intercrops always exhibit natural variation in their form and structure. Crown diameters are a key attribute that compliment plant heights in evaluating morphological habits of an AF intercropping system. Unlike maize whose lateral blades withered and lost turgidity, artemisia crown diameters remained horizontally erect at physiological maturity (Plate 5 and 6). Since longer crown diameters in intercrops could be associated with interplant competition for space, the difference between T_3 and T_4 may have been occasioned by their different plant densities. The insignificant effect of spacing on mean crown diameters may be attributable to the fact that all treatments did not constitute crowded conditions. These results thus suggest that two crops with similar agroecological adaptation but differing in height, canopy, and growth habits may grow simultaneously with minimum or negligible competition if proper spacing regimes are employed. As shrub canopy develops, the leaves of individual neighboring plants will start to intertwine and overlap in competition for light. Hay and Walker [1989] attributed this effect to an increase in levels of Gibberellins that promote leaf sheath extension for plant heights and crown diameters. By use of allometric equations or regression techniques and simulation which is beyond the scope of this study, these results may also help to predict how the intercrops can adapt to climatic changes through adjustments in morphology of different components under subhumid conditions.

5.2 Interplant Stand Density

Since closer spacing is associated with higher plant densities in an AF intercropping situation, spatial arrangements designed to optimise access to growth factors especially light reaching the intercropped plants in this study included semi-sequential planting of single hedgerows of artemisia fallows between maize rows. T_3 had the least while

T_4 and T_5 had the highest plant densities and total leaf yields of artemisia obtained from these densities were 279 kg ha^{-1} (T_5) to 763kg ha^{-1} pure stand. Total leaf biomass increased with higher plant densities hence closer spacing and this result is consistent with Simon *et al.*, [1990]; Woerdenbag *et al.,* [1994]; Duke *et al.,* [1994]; Laughlin, [1994]; and Delabays *et al.,* [2001], where plant population density and its components of inter- and intra-row spacing were used in determining yield and the practicability of both weed control and harvesting.

On average, plant densities in T_6 and T_1 recorded substantial grain yield per unit area, and since maize was generally less competitive than artemisia ($Mean\ CR_{Artemisia} = 1.3$; $CR_{Maize} = 0.8$), this could suggest that these two spacing regimes are suitable planting arrangements for farmers who have equal preference to both intercrops and have capacity to use commercial planting fertilizer Consequently T_3, T_4 and T_5 with the lowest mean grain yield per unit area of land, may represent plant densities that are not ideally suited for farmers who depend on maize as the main crop in an artemisia+maize intercrop. The farmer should be conscious of the fact that grain yields from components of the intercropping system depend on the spacing regime hence stand density. Therefore, by choice of planting arrangement, the farmer can manipulate interactions such as sharing of growth factors and genotypes, which ultimately may lead to increased yield [Francis, 1986].

5.3 Yield Components and Yield

5.3.1 Plant Biomass

Since 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, it suggests that the LR may be more ideal than the SR for this intercrop arrangement when plant biomass is the preferred attribute for yield advantage; but this aspect needs authentification through further testing for several seasons with respect to precipitation patterns. The effect of positive component interaction between the intercrops was more pronounced in T_3 maize, to result in high biomass yields of 2.78t ha^{-1}. This may be attributable to less crowding as the lowest plant density stand which enhanced a suitable microenvironment for optimal growth conditions for a facilitative component interaction. The highest biomass yield from T_7 maize at 3.85t ha^{-1} may be attributable to the effect of 'Niche differentiation' in favour of maize as was reported by Mkamilo, [2004]. The high biomass yield of artemisia obtained from T_5 (8.98t ha^{-1}), T_4 (9.67t ha^{-1}) and T_6 (7.03t ha^{-1}) apart from the control plot of T_8 with 9.65t ha^{-1} may have been possibly due to greater spatial complimentarity. These spacing regimes may represent plant proportions and densities that optimise total biomass yield through facilitative component interactions.

The lowest biomass yields at 5.39t ha^{-1} for artemisia T_3 may be attributable to low plant densities apart from the control of pure stands. Generally, closer spacing hence higher planting densities may have resulted in crowded conditions to induce high competition for critical growth resources, particularly as observed in T_1. The wider implication of these results is that if biomass is considered as a function of productivity, all the planting patterns used in this experiment except T_1, T_2 and the control of respective pure stands may be ideal intercropping options for practicing on farmers' fields depending on level of intensification desired. A similar observation on artemisia was made by Ochieng *et al.*, [2011], to the effect that artemisinin and leaf biomass production is influenced by cultivation environment, nutrient and crop management practices.

5.3.2 Chlorophyll Content

Leaf chlorophyll content may be a function of both soil and leaf N at any point in time during active vegetetative growth. However, the different spacing regimes did not affect the Chlorophyll content of either intercrop, suggesting that all the tested spacing regimes may not constitute crowded conditions to result in significant competition for radiation and soil nutrients especially N. This suggests compatibility or complimentarity in resource capture between the two intercrops of maize and artemisia. Significantly, there was a positive correlation between relative chlorophyll content and artemisinin sequestration of artemisia leaves towards the end of vegetetative growth period (r^2=0.7 according to *Pearson's Correlation Coefficient*). Similar results of correlation analysis revealed a significant positive correlation between plant height, crown-diameters and dry leaf biomass with artemisinin yield at pre-flowering and full bloom stage of artemisia [Yeboah, 2010], suggesting that AF intercropping systems or crop management practices that enhance yield components will have a positive influence on artemisinin production.

While there could be little basis for comparing the chlorophyll content of artemisia (*Asteraceae*) with that of maize (*Graminae*) in an intercropping situation as in this study, it may be worthwhile to note that maize is a C_4 [Paliwal, 2000] and artemisia is a C_3 plant [Marchese *et al.,* 2005]. This botanical difference may thus have contributed to the wide disparity between the two plant species in mean relative chlorophyll content i.e. 6.25 SPAD units for artemisia and 30.9 SPAD units for maize. According to Ehleringer *et al.* [1997], most plant species globally are characterized by C_3 photosynthesis and the proportion of C_4 production represents the outcome of interspecies competition between C_3 and C_4 plants. Even though maize was generally less competitive than artemisia (*Mean* $CR_{Artemisia} = 1.3$; $CR_{Maize} = 0.8$) in this study; the C_4 pathway is a modification of the normal photosynthetic process that makes efficient use of CO_2 available in the atmosphere, to the extent that plants using the C_4 pathway like maize can convert higher amounts of atmospheric C to plant sugars [Paliwal, 2000] than those with the classical C_3 (Calvin–Benson-Bassham Cycle) pathway like artemisia. The compatibility of C_4 and C_3 plants in AF systems for efficient photosynthesis have similarly been reported by Sikolia *et al.*, [2009] while working on *Amaranthus* species and *Kochia scoparia*, intercropped with *Chenopodium album* and *Phytolaca dioica* respectively to determine $C0_2$ compensation points. Higher biological yields and economic returns from shrub-based AF systems can thus be realised by partitioning the component species through niche differentiation, on basis of competitive abilities and photosynthetic mechanisms.

Leaf thickness affects the estimation of leaf N but in general, there is a strong linear relationship between SPAD values and leaf nitrogen concentration [Peng *et al.,* 1992]; and it may thus be possible to determine the plant's need for additional nitrogen fertilizer at a specific period in time during the growth cycle using SPAD values. The results indicate that the most appropriate harvesting time for artemisia was at the flowering stage, when the chlorophyll content was highest. Specifically, the positive correlation between chlorophyll and artemisinin sequestration, suggests that it is possible to manipulate N foliar application levels to improve artemisia leaf extracts. Maximization of artemisinin yield may require optimization of plant biomass through application of foliar N fertilization at critical stages of plant growth and development. 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.

5.3.3 Artemisinin content

The highest recorded mean artemisinin content from the trial was 0.88% (T_8) while the least was 0.70% from T_5 averaged over both SR and LR seasons. Treatments T_4, T_3, T_2 and T_6 in that descending order exhibited superior artemisinin % yield in the SR, suggesting that these spacing regimes are equally better than all the other treatments since they were not statistically different from each other. Since artemisinin is a secondary metabolite, climatic conditions, together with the way and time of planting and harvesting of artemisia can influence artemisinin production [Woerdenbag *et al.*, 1994; Ferreira *et al.*, 1997; Wallaart *et al.*, 2000; Marchese *et al.*, 2002] and this may help to explain why the artemisia crop grown in the short rains (SR) had higher biomass but less artemisinin content than the Long rains crop, on account of the weather variations experienced in the two seasons. The Maseno trial produced a mean artemisinin yield of 0.77% which is above the world average of 0.6% reported by Ferreira and Janick [2009]. Similar results were obtained by Woerdenbag *et al.*, [1994] in Vietnam who report that artemisinin is naturally produced in very low yields of not more than 1.5%.

Spacing in the LR season did not affect the artemisinin content but the mean was higher than in the SR. This may be attributable to overwhelming seasonal effect compared to the treatment effect. In addition, since water is the most limiting factor for plant growth, it can also trigger secondary metabolite accumulation depending on the plant growth stage. The amount of rainfall precipitation at critical time of growth was low during the Oct-Nov period for short rains' crop compared to the April-May period for the long rains' crop. The relatively high artemisinin content yielded in LR compared to SR may have been occasioned by mild water logging, to the extent that artemisinin accumulation may be related to the plants' mechanism of combating stress in this case occasioned by excess moisture. The higher rainfall recorded during the LR may thus have had an effect of inducing early flowering and accumulation of artemisinin at the expense of biomass. This is consistent with Marchese *et al.*, [2010] who observed that biomass and artemisinin accumulation are greatly affected by water content in the soil during seedling stage; and reliable rainfall or irrigation potential is essential for 2-3 months after transplanting where distribution is more important than absolute amounts. Several scholars have reported peak artemisinin accumulation at between bud initiation and full bloom [Woerdenbag *et al.,* 1994; Laughlin, 1994; Marchese *et al.,* 2002; Ferreira, *et al.,* 2005].

Maximization of artemisinin yield (amount per plant) requires optimization of plant biomass but the short rain season crop of artemisia yielded more biomass and less artemisinin than the long rains crop respectively. Biomass production hence artemisinin from artemisia species in either pure or mixed stands as influenced by seasonal variation has also been reported by Wallaart *et al.,* [2000] who found that the biomass of artemisia has seasonal dynamics with the peak yields reached in the last days of September in sub-humid ecozones. The plant content of artemisinin also varies during the season, independent of the developmental stage of the plant [Delabays *et al.*, 2001] but in this study, the insignificant yields within each of the two cropping seasons in artemisinin content is in concurrence with Ferreira *et al.,* [2005] who reported that unlike seed, vegetative propagation of artemisia will produce homogenous plants regarding artemisinin content. Artemisinin sequestration in leaves has been correlated with enzymatic activities in biosynthetic pathways [Wallaart *et al.,* 2000; Banyai *et al.,* 2010] and given the positive correlation between chlorophyll synthesis and artemisinin yield in this study, some applications of chlorophyll measures can thus be used in estimation of CR and ATER for croplands and agroforests where artemisia shrub is a component.

5.3.4 Maize Grain Yields

Generally, the mean LR yield of maize (3.2t ha^{-1}) was not significantly higher than the SR crop (3.16t ha^{-1}), but yield results obtained from this study including pure stand T_7 (SR=3.84t ha^{-1}, LR=3.77t ha^{-1}) were higher than the reported western regional average of 1.3t ha^{-1} [Hassan *et al.,* 2001] from farmers' practice. Maize grain yield in the intercropped systems was generally lower than in the monocrop probably as a result of the competitive effects of artemisia components in the intercrop for light, nutrients, moisture and space, since the population of maize was constant regardless of treatment. This corroborates the findings of Uddin *et al.,* [2003] and Allom *et al.*, [2010]. An increase in maize density from 3.7 to 5.3 plants per m^2 may result in yield increases by 10–30% under conditions without nutrient competition [Tetio-Kagho and Gardner, 1988]. However, the maize+beans system may have enhanced maize yields more due to the spatial arrangement of the intercrops, than due to differences in plant densities. Furthermore, assuming absence of intense inter species competition with maize+beans as compared to maize+artemisia, there may have been more efficient resource capture to facilitate vigorous growth and yield in the former system.

High yields in maize+bean intercropping systems as recorded in T_9 i.e. 4.7t h^{-1} and 4.3t h^{-1} for SR and LR respectively may be attributed to the effects of "Niche Differentiation". This observation is similar to Mkamilo, [2004] who while working on maize+sesame intercrops reported that the two component crops were partially complementary in resource acquisition; and Niche differentiation forms the basis for a yield advantage in intercropping. A comparative maize+beans system was also found by Woomer *et al.,* [2004] to allow more light penetration, which likely benefits the maize as well as the legume. The assumption here is that since the two species rely on the growth resources i.e. light differentially on account of their variation in height, then coexistence is possible and even facilitative when each species can tolerate a lower amount of only one resource compared to its competitor [Tilman, 1990]. The resource requirements and abilities for resource acquisition in maize+beans and maize+artemisia intercrops are not necessarily the same. However, even though niche differentiation and inter-specific competition may not always be related, Yield benefits from T_9 could be attributed to species complimentarity or minimal interspecies competition for growth resources particularly light than the N fixing attribute of the bean component. This is in tandem with Van der Meer, [1989] who postulated that biological yield advantage could result from low interspecies competition or strong facilitation.

T_1 maize yielded significantly high grain yields and since maize had a uniform plant population in all treatments, this yield advantage may be attributed to intense intraspecies competition between artemisia plants ($CR_{Artemisia}=0.85$), or complimentarity with artemisia for growth resources ($RVI_{Maize} = 1.6$) under this particular spacing regime. This intercropping arrangement could hence be ideal when maize is the main crop of focus in artemisia+maize mixtures. In contrast, T_3 recorded the lowest yields probably due to higher competitive ability of the artemisia component for growth resources ($CR_{Artemisia} =1.75$) in this spacing arrangement. All these results demonstrate that undesired plant species i.e. weeds may be controlled by modifying interspecific competition through variation in spatial arrangements or spacing patterns of maize+artemisia intercrops.

In general, maize yield variation recorded non significant indices during the long rains season compared to the short rains and while this was not entirely unexpected, very often the (SR) short rains are unreliable such that farmers rarely utilize it to grow maize [Birech *et al.*, 2008] unlike the (LR) long rains season. Due to the recent climate change phenomenon, various changes in the farming calendar are inevitable to suit intercropping patterns of maize and suitable component crops. It is now common to experience greater or equal yields from SR maize crop as opposed to the traditional LR that farmers have over the years relied on. Thus, any unfavorable climate change may add to the catalogue of short comings of monoculture maize cultivation to the extent that medium to long term investments in maize monocultures is now unpredictable without successful climate change adaptation efforts. The results from this study may therefore help to predict how maize cultivation should adapt to habitat changes through proper choice of companion crops, adjustments in planting times and densities, so as to result in desired yields of different components under subhumid environmental conditions. Furthermore, declining trends for productivity and a constant trend for area under maize cultivation will compensate for each other in the medium-term [Rojas, 2007]; and if maize is to be considered as the only food security crop, this may entail the need for alternative parameters for estimating the national food requirements.

5.4 Artemisia+Maize Component Interactions

An economically efficient intercropping system is also biologically effective but often, a biologically efficient system may not be economically viable [Ghulam et al., 2003]. Determination of intercrop yield advantages may thus not be validated by direct comparison of mean yields from pure stands in this study, on account of the varying results and different protocols that exist for assessing both biological and economic yield advantage from each crop component. The artemisia may also have benefited from the synergistic effect of applying compound fertilizer on maize. In addition, the ultimate yield of the intercrops was governed by weather characteristics besides management practices, to the extent that crop performance under these environmental conditions was also dependent on component interactions in the cropping system. These interactions were thus evaluated using RVI, CBA and derived parameters from LER of ATER, CR and LUE in order to consider and compromise between both the biological and economic yield attributes.

5.4.1 Land Equivalent Ratios (LER)

The productivity of the maize+artemisia versus maize+beans intercropping systems was evaluated using the parameter of land equivalent ratio (LER) for each of the treatments, by establishing comparative biological yields and suitable cropping mix of the intercrops with due regard to the experimental objectives. The critical value of LER is 1.0 whereby a

LER >1.0 indicates an advantage of intercropping over mono cropping while values of LER<1.0 show that is disadvantageous. A high mean L.E.R of 1.49 as represented by T_6 tells us that 49% greater yield for intercropping should be expected than if artemisia and maize were each planted in pure stands, or the total intercrop would have required 49% more land if component crops were planted in respective pure stands. In contrast, a lower LER of 1.15 as recorded from T_9 implies that only 15% greater yield from intercropping would be realised than monocrops of either maize or beans. Generally, similar LER values greater than 1.0 from intercrops have widely been reported, for example with maize+bean intercropping [Saban *et al.,* 2007]. Van der Meer [1989] further reported that where LER values are more than 1.0, there are positive biological component interactions suggesting that interspecific facilitation may be higher than interspecific competition. Numerous viewpoints related to component interactions suggest that since LER measures the levels of intercrop interference going on in the cropping system [Van der Meer, 1989], any negative interspecific interference that may exist in the mixture is not as intensive as the interspecific interference that exists in the monoculture of either maize or artemisia.

For LER purposes, T_7 and T_8 were controls for maize and artemisia respectively and while T_6 exhibited a superior spacing regime than the other treatments on basis of biological yield advantage during both growing seasons, it is worth to note that even the other treatments exhibited higher values than the controls at LER of unit value. The implication thus is that all the spacing regimes except the pure stands returned a yield advantage when using LER as an indicator. Since seasonal variation had no effect on partial LER values of both intercrops these results further suggest that the superiority of artemisia+maize intercrops versus the pure stands of each in a subhumid climate depends more on spacing hence proportionality of the mixture than season of planting. The LER indices thus indicate that system productivity favoured maize+artemisia than maize+beans intercrops. LER values also suggest that the artemisia+maize were more advantageous than the maize+bean system under the same management system, by a margin of 34% despite the presumed N-fixing capacity of the legume component in the latter mixture. This may be attributable to the fact that grain legumes contribute little or no N to associated crops because a large proportion (60-70%) of the N is removed during grain harvest [Giller *et al.*, 1998]. Furthermore, assuming absence of intense competition with maize+beans as compared to maize+artemisia, there may have been more efficient resource capture to facilitate vigorous growth and yield in the latter system to result in high LER values. Facilitative competition or partitioning of resources may also have occurred in favour of artemisia+maize compared to maize+bean intercrop mixtures, as was reported by Mazaheri *et al.* [2006], and Morgado and Willey [2008]; to the effect that crops sharing the same agroecological conditions for growth drives competing plant species into different patterns of resource mobilization and use, as in niche differentiation.

5.4.2 Area -Time Equivalent Ratio (ATER)

The ATER was derived from partial LER of the Long Rains (LR) assuming a fallow period of 45 days, and compared the relative productive capacities of each crop in the artemisia+maize intercropping systems, indicating which spacing regime is more efficient in the use of area and time to produce a given quantity of yield. However, LER is often based on desired yield proportions of the component crops predetermined at sowing and does not take into account the variation in crop maturity dates of each crop or biological complementarity for dry matter production [Putnam *et al.,* 1985] and duration of land occupancy. ATER [Hiebsch and McCollum, 1987] values may therefore present a more accurate estimation of yield potential or efficient use of growth resources for artemisia+maize intercrops as compared to LER values.

As in LER, the critical value of ATER is 1.0 where ATER >1.0 indicates an advantage of intercropping over mono cropping while values of ATER<1.0 show that there is no advantage by intercropping [Ofori and Stern, 1987]. Unlike LER which recorded T_6 as the most suitable index, an equally high ATER value of 1.0 as represented by T_4 compared statistically to the lowest ATER of 0.8 as represented by T_1 implies that both T_6 and T_4 are the most ideal intercropping arrangements and T_1 the least in terms of artemisia yield per unit area under artemisia+maize systems. The opposite may also be true for maize yields in the same treatments depending on planting densities or desired crop of preference, when area and time factors are taken into consideration. ATER values of less than one have been attributed to poor utilization of these resources [Khan *et al.*, 2001] as a result of intensive or unhealthy competition; whereas higher values of ATER in intercropped treatments compared with monoculture have been attributed to efficient utilization of natural (land and light) and added (fertilizer and water) resources [Muhammad and Khaliq, 2004] or greater temporal complimentarity for maize+bean intercrops [Gardner and Kisakye, 1990].

In general, the ATER values were lower than LER values in all treatments (Table 4.4), probably indicating the over estimation of biological land use efficiency with LER indices. While this may be as a result of the time factor involved with intercropping maize and artemisia biannually, the ATER results from this study further suggest that the superiority of artemisia+maize intercrops over maize+beans versus the pure stands of each component depends more on facilitative component interactions than seasonality. Similar observations were made by Allen and Obura [1983], Leihner [1983] and Banik and Bagehi, [1994] while working on cotton+cowpeas, cassava+beans and rice + pigeon pea intercrops respectively, and found the ATER concept to be a much stricter criterion compared to LER as determinants of system productivity by including area and time factors, and all of whom report that the implication of results from LERs values tend to be overestimated.

Consequently, the more ATER values approach LER, the more unproductive the intercropping system could be. Values of ATER from intercrops less than respective monocrops as compared to LER may also indicate a presence of extreme negative component interactions, and not a viable option when choosing suitable artemisia+maize intercrop mixtures for application of optimal land use practices. This is in agreement with Moseley [1984], who further explained that the biodiversity conservation benefits of agroforestry intercropping include the shortening of fallow periods that do not amount to any adverse consequences on system productivity. Generally, the results herein tend to confirm Giller *et al.,* [1991], that with reduced fallow periods due to increasing scarcity of arable land, claims of substantial transfer of N from legumes to intercropped plant species in either sequential or simultaneous AF systems on basis of high LER values may thus have been exaggerated in the past. When extrapolated to per Ha of land basis, there could be a significant variation in yields from each of these intercropping regimes as a result of overestimation of yield advantage using LER values.

Another significance of ATER results from this study may imply that if the artemisia component is planted simultaneously rather than sequentially in the intercrop (Plate 2), and used for other purposes other than medicinal, like woodfuel, adding organic matter to the soil, weed and/or erosion control, the maize yield will not be affected since its LER hence ATER will not be included in the calculations to result in significant biological benefits from the intercrop. Similar conclusions were made by Amede and Nigatu [2001], while intercropping maize and sweet potatoes, with the latter targeted for livestock feed.

With scarce arable land, AF intercropping systems could therefore optimise above ground benefits arising from the biotic component interactions by manipulating fallow periods created, when for instance a medicinal shrub like artemisia is intercropped sequentially with a food crop like maize in a cyclic annual rotation. Significant complementarity also occurs in an intercrop situation where the growth pattern of component crops should vary with time [Hiebsch, 1980].

5.4.3 Competitive Ratios (CR)

Intercropping not only alters the conditions available for the pure crop by competition but also influences the complementarity of one species over the other. The competitive ratio is an ideal means of determining the degree to which one crop competes with the other in an intercropping system [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; Ghosh, 2004]. Since both competition and interplant facilitation occurs in any intercropping system [Van der Meer,1989], CR could also be useful in comparing the competitive ability of different crops and determining what competitive balance between components is most likely to give maximum yield advantages [Willey and Rao, 1980].

On average, artemisia was 1.3 (or 30%) more competitive than maize during both the SR and LR cropping seasons in this study. It is noteworthy from CR values 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. However, T_1 maize was more competitive ($CR_{SR}=1.5$, $CR_{LR}=0.9$) than artemisia ($CR_{SR}=0.67$, $CR_{LR}=1.03$), to the extent that component interactions in T_1 resulted in significantly higher maize grain yields. Mean

T_1 maize had CR>1 implying that this intercrop arrangement may 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. T_1 intercropping arrangement could hence be more desirable for plant architectural arrangements or the most optimal combination for artemisia+maize intercrops if maize is to be considered as the main crop in the mixture for optimal grain yields. Shahid and Saeed [1997] also used CR values >1.0 to report that lentil was a better competitor when sown in association with wheat.

Maize CR was 0.8 on average relative to artemisia during both SR and LR seasons, indicating a negative biological benefit for maize within the artemisia+maize intercrop since maize was less competitive than artemisia. Higher CR values for artemisia as in the other treatments may suggest that the crop was a better competitor and utilized the growth resources more aggressively than maize, despite having been planted sequentially. T_3 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 as an intercrop. A similar observation was made for wheat (*Tritium aestivum*) by Zhang and Li [2002] while working with wheat+maize intercrops; and Mouneke *et al.*[1997], who reported a reduction in the growth and yield of okra and maize relative to their sole crops, where okra yield was depressed by maize.

Since artemisia T_3 had the lowest plant density, a possible implication of high T_3 CR values for artemisia+maize intercrop is that artemisia crops' in this spatial arrangement had slightly less than optimal space for growth and development, and may have concentrated on physiological mechanisms to fighting for growth resources especially light at the expense of biomass production. Banik *et al.,* [2000] also reported similar trends in competition and recorded depressed intercropping yields of mustard+pea, mustard+lentil, and mustard+gram mixtures over sole cropping. A similar result was also obtained by Dhima *et al.,* [2007] while working on vetch+cereal intercrops, and reported that competition can have a negative effect on the growth rate of the main crop species used in intercropping.

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. This argument corroborates that of Awal *et al.*, [2007], who report that as CR approaches Unit values intercrop associations in barley+peanut effectively counterbalance the competition for growth resources between these species. However, since the mechanism of the different competitive abilities between artemisia+maize intercropped plant species has not been recorded, the determination of this mechanism may assist in manipulating interspecific competition and opportunities for improved management practices that overcome production constraints and enhance intercrop productivity. These opportunities may include sowing date and spatial arrangements with respect to growth factors, in order to gain higher yield advantage of intercropping artemisia and maize. This corroborates with Mkamilo, [2004] who observed that over-yielding in intercropping systems may be occasioned by niche differentiation.

5.4.4 Replacement Value of Intercropping (RVI)

The Replacement Value of Agroforestry (RVA) 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 one year, the RVA index [Moseley, 1994] effectively reverts to the RVI [Van der Meer, 1989] to represent the extent to which the artemisia+maize intercrop is more or less valuable than the respective monocrop in an annual growth cycle. The RVI was determined in this trial to evaluate the relative economic yield advantage of maize and artemisia monocultures against respective intercrop replacements for the different spacing regimes, indicating which pattern was more or less profitable in the use of specific resources in the intercropping system. Since T_2, T_3, T_4, T_5 and T_6 were not statistically different from each other, but higher than T_1 and lower than T_8 the control, the mean RVI of 1.45 was used for artemisia from both the SR and LR seasons. This indicates that the profit from the intercrop is 45% higher than monocrops, to the extent that farmers who planted artemisia and maize could make a profit of 45% more than the farmers who are involved in monocropping of artemisia. This may be attributable to both the shortened fallow period and the consequent reduction or replacement in variable costs of labour and fertilizer that are associated with artemisia+maize intercrops.

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 (Plate 3). A similar observation was made by Kumar *et al.*, [1987], while studying the production of maize and associated intercrops in relation to spatial arrangements. 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. In this study, the increased benefit of the farmers involved in these intercrops may also be facilitated by more efficient use of growth resources, as well as reduction in the variable costs upto a maximum of 45%, 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 average RVI of 1.55 for maize recorded between the two seasons indicates that the profit from the intercrop is 55% higher than maize monocrops meaning that farmers who planted artemisia and maize could make a profit of 55% more than the farmers who are involved in monocropping of maize. A similar argument may also hold for artemisia via-a-vis maize, in addition to fact that higher RVI of artemisia (1.45) compared to maize (1.55) may suggest that replacing maize with artemisia will not add value to maize monoculture. This is further supported by the non-significance of the maize RVI values on the spacing regimes tested in this study. A similar observation was made by Alabi and Esobhawan [2005], while working on maize+okra intercrops, and concluded that any strategy that reduces cost of production in these intercrops will increase its profitability and attractiveness to farmers.

The increased profit (or gain) obtained in these intercrops may have been occasioned by shortening of the fallow period as was postulated by Moseley, [1994]; Or facilitated by reduction in variable costs by 45 to 55% as was similarly observed with Njoroge *et al.* [1993], who estimated the net benefit of intercropping coffee with food crops by accounting for total variable costs from the gross profits. Lower variable costs for artemisia than either maize or beans suggest that when similar intercropping treatments are used for the production of low-value crops such as maize, the higher maize yield from these technologies may not be sufficient to compensate for the higher total variable costs particularly of labour for beans and commercial fertilizers for the maize. As labour becomes scarce with respect to available land, AF intercropping may become more attractive due to the savings in cash inputs; and shrubs (as cash crop) increase in value relative to food crops cultivated by small scale farmers. By varying variable costs of maize and artemisia to derive Cost-Benefit ratios, successful intercropping may thus require that farmers design efficient systems in which complementary effects of intercropping on net returns exceed competitive effects [Ong, 1996].

5.3.5 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 and convenient to use or interpret by both farmers and extension. By using CBA, the potential benefits or loss of the intercropping system may be accounted for in increased yields, decreased input costs and/or a combination of both, so as to achieve food security and generate a cash income for the small scale farmer. The price offered to maize farmers during the duration of this study fluctuated greatly between Kenya Shilling (K*Sh*) 1800 in January and K*sh* 4600 in June, to average at K*Sh* 2500 per 90kg bag of Maize. The EABL offered K*sh* 40 kg^{-1} of dried Artemisia leaf with a minimum of 0.7% artemisinin content. Any leaf below this % threshold is usually rejected by the commercial buyer [EABL, 2005] and all values above this are priced equally. Since all treatments exceeded the threshold for artemisinin hence acceptable for marketing purposes, T_3, T_4, T_5, and T_6 intercrops whose value in thousands of K*sh* ha-1 were 79.2 82.5, 82.2 and 79.6 respectively may thus represent superior spacing regimes than the rest of the treatments including pure stands.

It is not biologically and economically feasible to undertake monocropping of maize (T7) with the prevailing spacing regimes and pricing levels, after the net benefit resulted in negative CBA value of 7.3. All treatments exhibited lower CBA values than the pure stand of artemisia T_8 implying that economic yield advantage was higher than biological yield. This may suggest that these spacing regimes are not economical when applying artemisia+maize intercropping for yield advantage over artemisia monocropping. Considering that the LER for T_8 resulted in unit value (=1.0) suggesting no advantage or disadvantage to intercropping, indicates that higher usage of inputs in intercrops hence high variable costs may not be commensurate with higher yields for artemisia intercropped with maize. A similar inference was been made by [Wubs *et al.,* 2005], that the productivity of intercropping systems is higher than in monocrops at low input application but this advantage decreases with increasing levels of inputs. CBA (for inputs versus marketable yield) indicates that the benefits of the intercropping far outweigh the maize monocropping costs to the farmer, but less so for artemisia monocrops, considering that the species planted is artemisia (without fertilizer) as a cash crop and maize (with fertilizer) for food security.

On basis of grain yield for maize and artemisinin content for artemisia, it may hence be reasonable to assume that the economic yield advantage from the intercrop may more or less follow a similar pattern with biological yield. However, when artemisia leaf yield (kg^{-1}) is the basis of such considerations, there could be significant variation between economic yield and biological yield of the artemisia+maize intercrop. Since T_8 (sole artemisia) recorded the highest CBA values than other treatments it confirms that biological yield advantage does not always imply an economic yield advantage. Similar observations were made by Ghulam *et al.,*[2003] while intercropping maize and soyabeans. T_3 recorded the highest CBA value compared to T_7 (sole maize) which had the lowest CBA value, and hence the difference between CBA values of T_7 and T_3 may effectively constitute in monetary terms, the optimal yield advantage of artemisia+maize intercropping system in this study. Furthermore, since T_1 and T_8 had the same artemisia plant density, the difference between T_8 and T_1 CBA value of 50.5 may reflect the optimal input level with variable costs for artemisia intercrops beyond which there is no additional yield advantage.

The CBA values indicate that the economic yield advantage for artemisia monocrop was more than the maize monocrop by Ksh 107,500.00 ha^{-1}, while maize+beans intercrop had the highest variable costs of Ksh 29.98 ha^{-1} occasioned by labour input and was marginally higher than the maize monocrop (T_7) by Ksh 43.9 ha^{-1}. Considering that maize is a food security crop with an intrinsic value in western Kenya, conception of cost-benefit rationales as a basis of profitability in artemisia+maize intercrops may also suggest that whereas complementarity exists, the economic consideration may undermine moral motivation for achieving food security from maize. Land use efficiency is compromised for attaining food security with maize. This is because biological yield advantage is not commensurate with economical yield benefit. Similar conclusions were derived by Wannawong *et al.,*[1991] who used cost-benefit analysis while studying AF systems consisting of Eucalyptus (*Eucalyptus camaldulensis*), 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. The variable costs in this study were greatly influenced by fertilizer and labour costs. On average, T_3, T_4 and T_5 with the lowest mean grain yield per unit area of land, may thus represent plant densities that are not ideally suited for resource poor farmers who depend on maize as the main crop in an artemisia+maize intercrop, unless external inputs like commercial fertilizer is timely applied. The opposite should hold for T_1 and T_6. On the other hand, T_3 represents the most ideal spacing regime on account of the expected economic returns from the artemisia+maize intercrop *in toto*, despite the fact that it recorded statistically non significant biological yield advantage with LER values of all treatments except the controls.

Results from this study using both the CBA and LER index as a measure of biological yield advantage of comparative intercropping systems may thus agree with Vanlauwe and Giller, [2006] who reported that even though Legumes are widely advocated as important sources of organic matter in cereal intercrops, not all of them are a source of free N on account of the intensive labor (hence higher variable costs) involved. Furthermore, complementarity of resources occurs when at least one of the component species of the association exerts a positive effect on the other [Fukai and Trenbath, 1993], and this study demonstrated lower variable costs for artemisia than either maize or beans This may suggest that the weed suppression ability of artemisia component resulted in no requirement for attendant labour costs, thus inflating the LER values.

5.4.6 Land Use Efficiency (% LUE).

Further confirmation of the existence or not of a biological yield advantage by comparing the LUE values between the seasons in each treatment was done by using the method of Rao [2002] as an average of LER and ATER values. For comparative analysis of yield advantage from the intercrops in this study, the CBA and LUE values are intertwined as a trade off process of identifying the most beneficial intercropping regimes. 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 been restored to a level sufficient enough to sustain a second crop. Similar observations were made by Van Noordwijk [1999] when testing the Trenbath model in shifting cultivation; and Louise and Tauer [1992] who further reported that intensification of land use by shortening fallow periods will initially increase returns per unit land at the opportunity costs of area under cultivation.

The critical value for LUE is thus 50% for each crop component and 100% for the intercropping system. The results suggest that all spacing regimes tested in this study with LUE values higher than 50% i.e. T_1, T_2 (Maize), T_3 and T_4 (artemisia), and T_6 (both artemisia and maize) were more advantageous in terms of land use efficiency. Ideally, the most efficient intercropping regime should record at least 100% LUE 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%. The results are also in general agreement with Scheidegger [2008] who observed that intercropping has at least 30% higher biological efficiency than sole cropping, while working on potatoes intercropped with various crops.

The LUE indices herein also demonstrate how each of the parameters studied will impact on the relative yield advantages of individual treatments within and between seasons, to the effect that intercropping facilitates efficient utilization of growth resources and helps to maintain greater stability in crop yields hence sustainability of the artemisia+maize AF system, depending on the choice of relative crop mix in the intercrop proportion. LUE values higher that 100% may indicate the presence of positive interferences or complementarity among the varieties or crop components of the mixture, as in T_3, T_4 and T_6. Alternatively this may also suggest that any negative interspecific interference that exists in the mixture is not as intensive as the intraspecific interference that exists in the monoculture of either maize or artemisia. Similar observations have been made by Zhang and Li, [2002] while intercropping wheat+soybean and Mason *et al.,* [1986] with cassava+cowpea polycultures.

Aggregate results from this study therefore suggest that if maize is the main crop in the intercrop, T_1 is most ideal cropping arrangements in terms of land use efficiency for food security and if artemisia is the main crop then T_3, T_4, T_5 and T_6 are the most ideal, since interspecific facilitation may have existed together in these spacing regimes as observed from CR and LUE indices. These spacing regimes have greater land use efficiency for respective crop of preference; and have more biological yield advantage which may presumably translate into higher net returns. If all crops in the mixture are of equal preference, T_3 which yielded the highest CBA value of 91.7 in Ksh '000 ha^{-1} and T_6 which recorded the highest total LUE value of 106.3%, and were statistically different from the controls of pure stands would be the most ideal spacing regimes, on basis of economic advantage and biological yield respectively; while T_1 with the least total mean LUE value of 95.4% would be the most unsuitable intercropping arrangement. However, since all the intercrops except T_9 were not statistically different from each other in terms of LUE (Table 4.6), the high CBA value resulting from T_3 may be more to do with cost saving than better harvestable yields. This is because the plant density in T_3 was lower to result in reduced costs of planting material and hence by extension, lower variable costs.

5.5 General Discussion

Due to lack of adequate diversification, the role of AF systems in enhancing biodiversity and livelihoods through intercropping maize and artemisia could be underestimated. The primary object of intercropping in this study was to achieve 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 reducing the yield of main crop is realised. Intercropping in the context of this study demonstrates production in a manner that will increase advantage from artemisia+maize to complement maize+bean production for food and nutritional security; so that if you wanted optimal yields from maize and artemisia, then the seeding rates of each crop component would be adjusted accordingly among the spacing options that were tested to produce those desired yields.

Since both competition and facilitation take place in many intercropping systems [Van der Meer, 1989; Zhang and Li, 2002] and yield advantage (if any) is dependent on net effects of facilitative and competitive interactions on growth resources [García-Barrios and Ong, 2004], the RVI index for AF intercropping experiments may thus be a determining factor in analyzing whether increased crop yields are due from shortened fallow periods, interplant complementarity or increased competition. However, results from this study seem to suggest that there are no negative component interactions with the spacing regimes tested. This could be expected since artemisia and maize belong to the *Asteraceae* and *Gramineae* families respectively, which may have different but complementary morphological characteristics like leaf venation and root systems, thus taking agroecological advantage of differentiated proximity to growth resources like light and soil nutrients respectively. Complementarity of resource use may also have occurred through synergistic effect of applying commercial fertilizer to maize intercrops. As with most medicinal herbs, artemisinin contents and efficacy are subject to climatic and geographical conditions, to the extent that not all artemisia plants necessarily contain sufficient amounts of the active ingredient, artemisinin [Marchese *et al.,* 2010].

From this research, and based on LER indices the maize+artemisia intercrops are generally more beneficial than maize+beans systems but these systems may prove even more productive since their component crops differ in growth duration to the extent that their maximum requirements for growth resources occur at different times to be manipulated. Thus, for high intercrop productivity, plants of the early-maturing component should grow with little interference from the late-maturing crop (Plate 3). In contrast, when growth durations of component crops are almost similar as in artemisia+maize, the crops compete more intensely for available growth resources. The LER, ATER, CR and RVI values gave an indication as to relative yield performances and competitive or complimentary abilities that can then be manipulated by variation in growth environment for desired yields in either SR or LR cropping seasons. Results from these biological yield parameters suggest that all the tested spacing regimes in this study may be suitable for application depending on the level of intensification desired by practicing farmers. The production of a system depends not on the efficiency of individual component crop of the system but also how well these crops compliment with each other in time and space [Willey and Reddy, 1981]. LER in isolation could thus be unsuitable as a basis for recommending the optimal planting densities or spatial arrangements for small scale and resource-poor farmers with limited capacity to use external inputs such as commercial fertilizer and herbicides. Similar arguments were made by Chabi-Olaye *et al.*, [2005], while comparing LER, ATER, and RVI values of Maize intercropped simultaneously with Cassava, Cowpeas and Soybeans.

There is a natural tendency for farmers in western Kenya to invest in lower value commodities like maize because of their intrinsic value of ensuring food security despite their high variable costs of production as in this study. Maize commodity prices in Kenya are highly elastic in the local market, and are determined by forces of supply and demand subject to the government's policy at any point in time [Pearson *et al,* 1995]. In good harvest periods the prices drop due to increased supplies, but when the harvests drop prices tend to rise steeply. Since artemisia monocrop was more profitable than all intercrops on basis of CBA, the wider implication here is that biological yield advantage as postulated in this study may not translate to economic yield advantage for maize. This is in concurrence with Ghulam *et al.*,[2003] who reported that a biologically efficient system may not be economically viable, and hence not suitable to be recommended for wide scale adoption by farmers before careful consideration of available options.

As for artemisia, it is possible that high profit commodities like medicinal shrubs may experience high price volatility and therefore present high production risks, to the extent that small variation in prices may make the production unprofitable or not in the long term. Furthermore, depending on the soil properties and rainfall patterns, the artemisinin content may be very low and without economical value in certain places. The economical range in East African content of artemisinin by bioassay is 0.60-1.2% [EABL,2005]; and contents below 0.6% are of negative commercial value owing to the prohibitive cost of processing the end product [Technoserve Inc., 2004]. Heemskerk *et al.,* [2006] reported that without wide fluctuations in demand of artemisinin for malaria control and a system of guaranteed market outlets, the price of artemisinin might stabilize to US$ 250- 300 kg^{-1} in the medium to long term. The average artemisinin content of leaves from all the treatments in this study except the control was 0.77%, corresponding to a yield of about 15.4kg ha^{-1}. Farmers producing upto 15.4kg ha^{-1} of artemisinin, translates to an average income of Ksh.85,000.00 ha^{-1} at current exchange rates, but these may change with time as market forces oscillate or agronomic practices improve further. If small scale farmers in western Kenya can embrace farming as a business, the biological yield advantage may thus constitute an economical yield advantage for artemisia unlike maize. Since T_3 was the best spacing regime on account of expected economic returns, an optimal combination of artemisia+maize system using this spacing is a favourable proposition for yielding tangible economic benefits from subsistence farmers without compromising on food security or the aesthetic attachment farmers in western Kenya have to maize cultivation or "The Maize Syndrome".

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 agroecological profiles as western Kenya. This is because shrubs like artemisia have great potential for diversification and can play a crucial role in sub-humid agroecosystems in adapting to climate change and providing a range of products like medicine, woodfuel and services like paid labour to rural populations with contract farming as an agribusiness. As ‘fallow land’ and ‘fallow periods’ for agriculture development diminish towards minimum feasible limits, the benefits accruing from agroforestry can sustainably be enhanced by integrating artemisia monoculture shrubs (Plate 4) into maize production systems at farm and landscape levels.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

- The CBA, LER, ATER, CR and RVI results from this study indicate that both maize and artemisia are compatible for an intercropping system of farming in a sub-humid tropical climate like western Kenya, where interspecific competition and facilitation existed simultaneously.
- The maize+artemisia system resulted in a higher yield advantage than maize+beans intercrops, based on CBA and LER indices. Since artemisinin is unlikely to be produced economically by chemical synthesis or by *in vitro* production, artemisia has great potential as a cash crop for intercropping with maize in sub-humid areas of Kenya.
- When maize is the main intercrop on basis of desired grain yields given the small land sizes, a spacing regime of T_1 (*1m Artemisia **X** 1m; Maize 0.90m **X** 0.75m*) is most ideal and guarantees a minimum gross income from artemisia of Ksh 65,800ha^{-1}
- T_5 (*Artemisia 0.9m X 0.75m ; Maize 0.9m X 0.75m*) *and* T_6 (*0.90m Artemisia X 0.9m; Maize 0.90m **X** 0.75m*) exhibited superior spacing regime based on majority of parameters studied and were not statistically different from T_3 (*1m Artemisia **X** 0.9m ; Maize 0.90m **X** 0.75m*) with the highest economic benefits. Thus, T_3, T_5 and T_6 are the most suitable spacing regimes for farmers intercropping artemisia+maize and depending on desired level of intensification.

6.2 Recommendations

I. Due to the small average farm sizes in Maseno area of western Kenya and high capacity for intensification hence the need for optimal land use practices, the most suitable spatial arrangements from this study ranges from T_3, T_4, T_5 and T_6 *i.e.* [*1m Artemisia **X** 0.9m ;* Maize 0.90m **X** 0.75m ; *Maize 1m **X** 0.75m];[0.75m Artemisia X 0.75m ; Maize 0.75m **X** 0.90m]; [0.9m Artemisia X 0.75m ; Maize 0.90m **X** 0.75m]* and *[0.9m Artemisia **X** 0.9m ; Maize 0.90m **X** 0.75m]* with single seeding of maize in each arrangement. These spacing regimes provided the greatest land use efficiency and high replacement value among all the tested cropping patterns in both seasons.

II. For farmers with a preference for artemisia or maize, a spacing regime of T_3 (*1m Artemisia X 0.75m; Maize 0.90m X 0.75m*) or T_1 (*1m Artemisia X 1m; Maize 0.90m X 0.75m*) respectively will be ideal; Artemisia T_3 is superior on basis of CBA while Maize records high CR and RVI values. For farmers with more intensified forms of Intercropping, a spacing regime of T_4 (*0.75m Artemisia X 0.75m ; Maize 0.90m X 0.75m*) and T_5 (*0.90m Artemisia X 0.75m ; Maize 0.90m X 0.75m*) is recommended if extra application of commercial foliar fertilizer is applied at critical growth stages prior to harvest to produce high artemisinin content.

III. For sustainable crop production to generate farm incomes, agroforestry practices by farmers involving contract farming with ACT drug manufacturing companies can profitably cultivate artemisia plants as intercrops with maize bi-annually to generate farm incomes of Ksh 79,200 to 82,500 Ha^{-1} each planting season and also guarantee food security from maize.

6.2.1 Suggestions for Further Research

I. Work on AF fallows in western Kenya has focused on a few genera of fertilizer shrub/trees but there is need for continued diversification and upscaling of research on alternative species like artemisia to include maize+beans+artemisia system with potentially great socio-economic impact on end-users.

II. Maximization of biomass production against leaf artemisinin concentration to achieve optimal yield per plant of the active ingredient; and to focus on selection of high artemisinin producing cultivars of *Artemisia annua* L, adapted to different AEZ of Kenya through Biotechnology.

III. Agroforestry land-use systems have been reported to have large potentials to sequester soil carbon and adapt to climate change, hence more studies in western Kenya need to determine Carbon sequestration in fallows enriched with artemisia shrubs.

IV. Other research on the artemisia + maize intercrops:

a. The possible combinations of stand establishment with respect to temporal, spatial and sequential attributes of intercropping, with further variation of crop densities and fertilizer application regimes.

b. Allelopathic potential of artemisia in weed control and other component interactions for optimal productivity in food crops to suit the resource base of small scale farms.

c. Regression techniques to isolate intra- and inter-specific competition to predict more accurately the yield response of maize and artemisia over a range of other plant densities of the two crops grown as an intercrop.

d. A study on potential sustainability of maize+artemisia adoption.

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