



## Refining Dryland Farming Systems as a Means of Enhancing Agrodiversity and Food Security in Eastern Kenya: A review.

Nguloo, S. N.\*<sup>1</sup>, Karanja, J.<sup>3</sup>, Kimatu J.N.<sup>1</sup>, Gicheru, P.T.<sup>2</sup>, Musimba, N.<sup>1</sup>, Njiru, E.<sup>3</sup>, Kathuli, P.<sup>3</sup>, Nzioki, H.<sup>3</sup>, Akuja, T.<sup>1</sup>, Muli, B.K.<sup>1</sup>, Nzombe, N.N.<sup>4</sup>

Corresponding author, Email: nguloo@yahoo.com

<sup>1</sup> South Eastern Kenya University, P.O. Box, 170-90200, Kitui, Kenya

<sup>2</sup> National Agricultural laboratories, P.O. Box 57811, Nairobi Kenya

<sup>3</sup> Kenya Agricultural Research Institute, Katumani Research Centre, P.O. Box, 340, Machakos, Kenya

<sup>4</sup> Ministry of Agriculture, P.O. Box 27-90100, Machakos, Kenya

### Abstract

Drylands which cover one third of the earth's land surface and almost 80% of Kenya's land surface are being used to grow dryland crops such as maize, beans, sorghum, millets and livestock. Studies show that refined farming systems can be used in enhancing ecosystem sustainability, through the promotion of species and crop diversity. For example, cropping patterns involving intercropping legumes and cereals have demonstrated varying success in maintenance of crop diversity in the Kenyan drylands showing land equivalent ratios (LER) > 1.0, although such benefits are often lost during low rainfall seasons. Research show that some genotypes can be used to reduce soil erosion, enhance nutrient availability, soil moisture retention, microbial earthworm activities and land use efficiency. Thus critical examination of farming systems for dryland areas suggests that long term multiple effects of the ecosystem, rather than the short term benefits not only increases yields but sustains the life of ecosystems. In this review we submit that monocropping systems should be modified to include varieties that are suitable for different plots in the same site to enhance efficient utilization of underground diversity. In developing farming systems modelling approaches utilizing plant genotypic and epigenetic variations, ecological, edaphic and microbial cycles should be evaluated for dryland ecosystems.

**Key words:** farming systems; monocropping; agrodiversity; food security; dryland.

# Council for Innovative Research

Peer Review Research Publishing System

Journal: JOURNAL OF ADVANCES IN AGRICULTURE

Vol.3, No.1

[jaaeditor@gmail.com](mailto:jaaeditor@gmail.com)

[www.cirjaa.com](http://www.cirjaa.com)



## Introduction

Millet and sorghum are some of the major crops that came from the African drylands. The Mediterranean basin has given the world date palm and olive trees (CCD Secretariat, 1997). Drylands continue to provide new food, as traditional food products are increasingly becoming commercialized globally in the age of health-consciousness (e.g. wild millet and wild rice). Globally, it is estimated that these ecosystems cover one third of the earth's total land surface and about half of this area is in economically productive use as range or agricultural land (CCD Secretariat, 1997).

Drylands in Kenya occupy about 80% of Kenya's land surface and because of their vastness, they have an immense scientific, economic and social value. They are the habitat and source of livelihood for about one quarter of Kenya's population. Furthermore, dry lands of eastern Kenya, cover about 6 percent of the land mass of the country (GoK, 2009). The altitude ranges from 440 to 1800 metres above sea level (masl) and the unreliable rainfall ranges from 500 to 800 mm annually, with a coefficient of variation of 45% (Keating *et al.*, 1992) and an agricultural growing period of 60 to 120 days. Temperatures vary between 20-35°C with pan evaporation rates of 4-9mm per day. Dry lands suffer from annual moisture deficits of greater than 50% and are considered the most threatened by land degradation (Mugagga *et al.*, 2010) due to their fragile soils that have poor nutrient content and weak structure prone to soil erosion. It is estimated that about 8 percent of the population in Kenya, estimated at 42,373,022 (GoK, 2009), currently live in the eastern dry lands of the country. It is important to note that the population of these areas is continually increasing, with the majority moving from the highlands, where population is overflowing, to the dry lands exacerbating resource degradation and aggravating the food problem.

Dryland pastoralists and crop farmers in Kenya have developed efficient pastoral and mixed cropping systems adapted to the difficult conditions of drylands (Bakhtri *et al.*, 1983; Gachimbi *et al.*, 2005, De Jager *et al.*, 2005). They have successfully created and maintained high levels of agrobiodiversity of crop species and livestock breeds. The drylands face increasing threats of further degradation and loss of biodiversity, especially with the looming climatic change. Research conducted in the semi-arid areas of Kenya appear to address only short term problems rather than the long term questions (Anon, 1995, Itabari *et al.*, 2004). Therefore, drylands need urgent attention and new paradigms are needed to go beyond the status quo. This paper describes the farming systems that exist in the drylands of Kenya and offers suggestions for improvement and sustainable use of dryland biodiversity to enhance food security.

## The development of traditional farming systems in Eastern Kenya

During the early 19th century, the Akamba who inhabit the drylands of Eastern Kenya, were settled in the hill masses, while the pastoral Maasai were roaming the plains ensuring that they were not occupied by the other tribes for their livestock. The Akamba grew red cobbled maize, beans, sorghum, cassava, sweet potatoes, millets and cowpeas and herded local cattle. Rains failed periodically and serious famines were recorded (O' Leary, 1984). There was continuous conflicts between the two tribes. As the conflicts with the Maasai subsided in the 20th century, other tribes settled in the plains and continued with the traditional crop and livestock farming systems. Studies by Bakhtri *et al.* (1983) recognized farming systems in terms of cropping and the livestock kept. They identified three cropping systems and one livestock production system. Other studies (Anon, 1995) identified seven production systems based on amount of rainfall, crops and livestock. This categorization followed the agroecological zones (AEZ) scheme described by Jaetzold and Schimdt (1983). The various systems identified were characterized by supplementary crop-livestock interactions (Jaetzold and Schimdt, 1983). Majority of the farmers in these farming systems grew annual and perennial crops under rain fed conditions and limited irrigation (Gachimbi *et al.*, 2005, De Jager *et al.*, 2005). They also kept indigenous animals of low genetic potential which were fed on natural pastures and crop residues (Tessema and Emojong, 1984). Later, De Jager *et al.* (2005) classified the farming systems in terms of rainfall and population density as rainfed-low population density areas (RAIN LOW); Rain fed systems in high population density (RAIN HIGH) and irrigated systems (IRR). One characteristic of these systems was that products produced from crops and livestock were consumed on the farm or traded in the local markets often for low returns, due to the limited access to marketing outlets and infrastructures (Muhammad and Parton, 1992).

Productivity in these farming systems was low because the soils are low in fertility resulting in low crop and livestock yields (Simpson *et al.*, 1992). The presence of low organic matter and high sand proportions in the soils rendered them susceptible to surface sealing and capping (Okwach and Simiyu, 1999). Continuous cropping using oxen without replenishment of nutrients has resulted in formation of hardpans (Biamah *et al.*, 2003) and nutrient mining (McCown *et al.*, 1992; Okalebo *et al.*, 1992). Besides, some of the soils that have been irrigated for several years are showing signs of salinization (Sijali *et al.*, 2003).

## Analysis of the various farming systems in the ASALs

The major components in the drylands of Kenya are crops and livestock which are dependent on the natural resource base of soil, water and vegetation. The crops grown are normally legumes such as beans, cowpeas, green grams and pigeon peas. The livestock kept include; sheep and goats (shoats), cattle, donkeys and chicken. In each of the farming systems outlined, farmers plant a mix of crops that will ensure at least some yield despite extremes of climate, pests, disease, labour shortage or other constraints. The growing conditions allow a wider range of crops. The main food crops grown under rainfed farming are maize, sorghum, millets, beans, cowpeas, green grams and pigeon peas (Table 1). These are accompanied by other cash generating crops that include coffee, horticulture, agroforestry and raising of dairy animals under zero and semi-zero grazing systems in the relatively high rainfall areas.

**Table 1. Types of farming systems and their components in the different agro-ecological zones (AEZ) in Eastern Kenya**

| Farming system | Major crop components   | Major livestock components | Agroecological zones (AEZ) | Rainfall (mm/yr) | Examples of areas where found                             |
|----------------|---|----------------------------|----------------------------|------------------|---|
| 1              | Maize, beans  | Dairy cattle               | LH2, UM3-LM3               | 800-1000         | Hill masses of Mbooni, Iveti, Ngong, Central Kitui        |
| 2              | Maize, beans, pigeon peas                                       | Cross-bred dairy           | UM4-LM4                    | 600-800          | Mwala, Wote, Nzambani, Migwani, Loitokitok                |
| 3              | Maize, cowpeas, pigeon peas, beans                              | Cross-bred dairy           | UM 5                       | 500-700          | Chumvi in Machakos district                               |
| 4              | Sorghum, millet, cowpeas, pigeon peas                           | Local cattle               | LM 5                       | 450-600          | Kamuwongo in Mwingi, Kyuso districts, Zombe Eastern Kitui |
| 5              | Sorghum, millet, green gram, cowpeas, pigeon peas               | Local cattle               | LM 5                       | 400-600          | Masinga, Kajiado, Kiboko                                  |
| 6              | Sorghum, millets  | Local cattle               | LM 6                       | 300-500          | Mtito Andei, Kajiado                                      |
| 7              | Irrigated agriculture (Tomatoes, onion, asian vegetables grown) |                            | LM 4, LM5, LM 6            | irrigation       | Matuu, Kibwezi, Loitokitok                                |

Adapted from Anon, 1995 and De Jager et.al. 2005

### The current situation of the farming system in Eastern Kenya

Currently, the cultivated fodders and pastures are not extensive. The arable land set aside for production of fodder is seldom more than 0.1 ha. In the drier areas, farmers keep local cattle, few cross-bred cows and shoats. In crop production, farmers plant a combination of different crops in different fields. In each crop they select varieties that enhance their food security and some economic advantage. They select crops and varieties using different criteria – some strains will be selected because they are high yielding in optimum conditions, others because they are tolerant to drought and others due to their resistance to storage pests. Additionally, they are also chosen because of the high market price, good taste or are easily processed. Each selection involves an assessment of the potential risks and rewards of planting a particular crop or variety. Such decisions are influenced not only by the physical characteristics of the environment, but also by socio-economic factors such as available labour and proximity to markets. Farmers view the selection of crop varieties as a continuous process. Some varieties that are tried in the field become part of the farmer's own landrace, whereas others, whose characteristics prove to be less suited to the local environment, quickly disappear from the field. Combinations of crops and varieties that continue are those identified as being a best match for the field conditions, intercropping compatibility, the wider environment and the farmer's own situation. National dryland researchers in Eastern Kenya, learned early (Anon, 1995) that while they may breed for high yields, drought tolerance and pest resistance, farmers consider a wide range of other characteristics. Thus they adopted the use of participatory methods in their research process (De Jager et.al. 2005; Mulwa and Nguluu, 2003), where the end users are involved in the research process from the beginning to the end.

Researcher-farmer participation culminated in most of the farmers planting more than one variety of maize, sorghum, beans, and cowpeas on their land. This scattering of plots reflects not only risk-spreading decisions, but also the matching of particular varieties to the different biophysical characteristics. Crops that perform well under well fertilised plots are planted on the well manured fields near the homestead (Probert, et al., 1992).

The choice of the livestock kept is also based on diversity. Farmers in the arid and semi-arid lands (ASALs) keep both pure milk breeds, cross breeds and/or local breeds depending on the local environment and individual management. In the drier areas, farmers keep local zebu cows and shoats that add to the animal diversity. Pastors have learned that when drought is severe shoats have better survival mechanisms than cattle. The choice of grass species is based on their performance in the environment. Farmers in the ASALs allow different grasses to grow together to guard against failure. The commonest grasses include *Cenchrus ciliaris*, *Enteropogon macrostachyus* and *Eragrostis superba*.



## Possible Research interventions using agrodiversity to improve food security.

Biologists most often define agro-diversity (Gaston and Spicer, 2004) as the totality of genes, species, and ecosystems of a region. An advantage of this definition is that it seems to describe most circumstances and present a unified view of the traditional three levels at which biological variety has been identified, namely: genetic diversity, species diversity and ecosystem diversity. The concept of agrodiversity can be taken to mean crop and livestock diversity which are characteristic of most farming systems in the drylands of Kenya, commonly referred to as the arid and semi-arid lands (ASALs). Diversity in cropping systems is shown by the varieties that are grown and the different cropping systems. In livestock, different breeds and categories of animals are kept. Crops and livestock have interactions that involve soil micro flora and fauna.

Dryland researchers in Kenya have over the last decade made efforts to develop participatory methods of developing farming systems that fit the conditions of dryland ecosystems. In the context of biodiversity, intercropping is relevant and has been viewed as a contributor to food security in the ASALs. The benefit of intercropping is expressed as land equivalent ratio (LER) (land use advantage), which is defined as (yield of first intercrop / yield of the first sole crop) + (yield of second intercrop / yield of second sole crop). For instance, if maize and beans are intercropped, and then yield of sole maize is given as 2604 kg/ha and that of sole beans as 824.6 kg/ha and that of maize intercropped with beans as 1573.7 and 610.5 kg as the yield of beans under the same intercrop, then the LER would be  $(1573.7/2604) + (610.5/824.6) = 1.34$ . A LER > 1 shows an advantage of intercropping compared to sole crop. In our example, intercropping had a 34% advantage over monocrops of maize and beans. In other words, it is more advantageous (34%) to use the land to grow the maize/bean intercrop that grow pure stands of either maize or beans.

Cropping patterns involving intercropping legumes and cereals have demonstrated varying success in maintenance of crop diversity in the Kenyan drylands. Intercropping has been shown to produce LER above one depicting yield advantage over monocrops during seasons with adequate rainfall (Thairu and Ariithi, 1987). However, those benefits were lost during low rainfall seasons (Table 2). Thus, though crop diversity is beneficial in promoting agrodiversity, it may not always be the best approach to maximize yields in dryland areas. Studies have shown that growing different species and genotypes adapted to specific ecological niches in different fields may increase yield as well as promote diversity (Kaihura and Stocking, 2003) in a site. Maize/cowpea intercrop, produced lower maize yields than maize/bean intercrop indicating the importance of making the right choice of intercrops (Nadar, 1984). Spatial arrangements under intercropping vary in yield due to competition between the components. Nadar (1984), working in the drylands of eastern Kenya, found that intercropping maize with beans in the same row resulted in lower intra-row competition than competition between rows of maize and beans. Similarly, when maize was intercropped with long duration pigeon pea it was 60% better than sole crop maize. However, in other studies (Tarhalkar and Rao, 1981), maize intercropped with short duration pigeon pea did not show any advantage, emphasising the genotype effect. Clearly there is need to identify adapted genotypes that can promote crop diversity. Therefore the new crop genotypes should be tested for combinability under intercropping situations because farmers in the ASALs will continue the practice despite recommendations for monoculture. In the relatively higher rainfall areas where some farmers may wish to practice monoculture, different genotypes should be identified for inclusion in specific fields to enhance productivity.

**Table 2. Land equivalent ratios (LER) of Maize/bean (M/b), Maize/cowpea (M/cp), Maize/pigeon pea (M/pp) and Sorghum/bean (S/b), Sorghum/cowpea (S/cp), and Sorghum/pigeon pea (S/pp) cropping systems in the short (SR) and long rain (LR) seasons**

| Season | M/b  | M/cp | M/pp | S/b  | S/cp | S/pp | Source                   |
|--------|------|------|------|------|------|------|--------------------------|
| SR     | 1.34 | 1.1  | 1.30 | 0.90 | 1.02 | 0.88 | Thairu and Ariithi, 1987 |
| LR     | 0.74 | 1.0  | 1.30 | 1.07 | 1.23 | 1.01 |                          |
| SR     | 0.71 |      | 0.82 | -    | -    | -    | Nadar, 1984              |
| LR     | 1.00 |      | 1.14 | -    | -    | -    |                          |

## Effect of farming systems involving intercropping on natural resource base

Intercropping is the agricultural practice of cultivating two or more crops in the same space at the same time (Andrews & Kassam, 1976). It has influence on micro-environment, erosion (van Duivenbooden, 2000), soil nutrients and microbial populations.

Studies by Olanitan *et al.* (1996) showed that radiant energy reaching the soil surface and maximum diurnal soil temperatures were lower with intercropping, with the lowest values being observed in the fertilized plots. Similarly, soil moisture content and earthworm activity were greater with intercropping, with the highest values occurring in fertilized plots. In South Africa, Tsubo *et al.*, (2003) found that the total LERs for maize yield and growth ranged between 1.06 to 1.58 and 1.38 to 1.86 respectively, showing yield and growth advantage of intercropping. Concerning radiation and water use, the intercropping of maize and beans had both radiation and water use efficiencies (RUE and WUE, respectively) as high as maize sole cropping, and intercropping RUE and WUE were greater than bean sole cropping. It was concluded from these results that maize-bean intercropping can be recommended to small-scale farmers.



Cropping systems play a role in reducing soil erosion. For example, in Burkina Faso, a mixed crop of sorghum and cowpea reduced runoff by 20-30% compared to sorghum alone, and by 5-10% compared to cowpea alone, resulting in a reduction in soil erosion of 80% and 45-55%, respectively (Zougmore *et al.*, 1998). In South Africa, Haylett (1960) found soil loss to be 44 times higher under continuous maize cropping compared with natural vegetation.

Legumes in intercropping systems can contribute some residual nitrogen to the subsequent crop (Willey, 1979). However, low-growing legumes are often shaded by taller cereals (Dalal, 1974; Chang and Shibles, 1985; Manson, *et al.*, 1986) and under smallholder management in low-fertility conditions, poor emergence and growth of the intercropped legume is common. This limits the N and organic matter contribution of the legume on farmers' fields to levels well below the potentials found on research stations (Kumwenda *et al.*, 1993; Kumwenda, 1995). One of the more promising intercrops is late-maturing pigeonpea. Even though early growth of the legume is reduced when it is intercropped with maize, pigeonpea compensates by continuing to grow after the maize harvest and produces large quantities of biomass (Sakala, 1994). In Malawi, Sakala (1994) reported a pigeonpea dry matter yield of 3 t/ha from leaf litter and flowers when pigeonpea was intercropped with maize. Pigeonpea is easily intercropped with cereals and, even if the seed is harvested for food, the leaf fall is sufficient to make a significant contribution to N accumulation. The disadvantage is that pigeonpea is highly attractive to livestock and impractical to grow where livestock are left to roam the fields freely after harvest, a common practice in many African smallholder systems.

The importance of intercrops in densely populated regions is widely recognized. Intercrops have a stabilizing effect on food security and enhance the efficiency of land use. However, in semiarid areas, plant densities (and thus potential yield per hectare) must be reduced in intercropping systems (Shumba *et al.*, 1990). Cowpea/maize intercrops greatly reduced the grain yield of maize in dry years. Natarajan and Shumba (1990), reviewing intercropping research in Zimbabwe, observed that cereal-legume rotations appear to offer greater prospects of raising the yield of cereals than do intercrops. Whereas maize benefits from being grown after groundnuts (*Arachis hypogaea*), maize-groundnut intercrops often reduce maize yield (Hikwa and Mukurumbira, 1995). Cowpea-maize intercrops yield better than either maize or cowpea sole crops on a land-equivalent basis in wetter areas of Zimbabwe (Mariga, 1990). Similarly, intercropping with non-nitrogen fixing tree crops have been shown to have benefits. Intercropping of chestnut with cereals had a better fertility in the upper horizon, compared to those without intercropping (Queijeiro, 1997). Such intercropping systems which combined chestnut trees and cereals, had some advantages also from the point of view of long term sustainability.

Intercropping influence microbial activity in the soil. Long term field experiments carried out at two sites having 38- and 10-year-old orchard cropping systems under sub-tropical climatic regions showed that under a system of different intercropped fruit trees, the cultivation of coconut (*Cocos nucifera* L.) intercropped with guava (*Psidium guajava* L.) enhanced the soil microbial activity approximately 2-fold after 38 yrs and over 10 yrs of the same intercropped system. Soil organic carbon increased from 3.4 to 7.8 and 2.4 to 6.2 g kg<sup>-1</sup> after 38 and 10 yrs, respectively, following the establishment of orchards (Manna and Singh, 2001). The increase was attributed to greater recycling of bio-litters. Levels of dehydrogenase, phosphatase and soil microbial biomass under field conditions generally depended more on the nature of the cropping system than on soil types. Similarly, average carbon inputs of bio-litter to the soil in monocrop (0.98 Mg ha<sup>-1</sup> yr<sup>-1</sup>) was less than intercropped fruit trees (2.07 Mg ha<sup>-1</sup> yr<sup>-1</sup>). The average level of soil microbial biomass carbon was 1158 kg ha<sup>-1</sup> (0–0.15 m depth) and the organic carbon turnover rate was 8.5 yr<sup>-1</sup> after 38 yrs of intercropped fruit trees, which resulted in a lower ratio (1.81) of carbon inputs to soil microbial biomass carbon.

Positive effects on soil organic matter and physical properties are enhanced under mixed cropping systems. The intercropping system of tree with soybean in juvenile plantations, as a short-term practice, demonstrated that larch (*Larix gmelinii*)/soybean (*Glycine max.*) and ash (*Fraxinus mandshurica*) intercropping systems improved soil physical properties after soybean intercropping with larch and ash in one growing season (Manna and Singh, 2001). The soil bulk density in larch/soybean and ash/soybean systems was 1.112 g·cm<sup>-3</sup> and 1.058 g·cm<sup>-3</sup>, respectively, which was lower than that in the pure larch or ash plantation without intercropping. The total soil porosity also increased after intercropping. The organic matter amount in larch/soybean system was 1.77 times higher than that in the pure larch plantation, and it was 1.09 times higher in ash/soybean system than that in the pure ash plantation. Contents of total nitrogen and hydrolyzable nitrogen in larch/soybean system were 4.2% and 53.0% higher than those in the pure larch stand. Total nitrogen and hydrolyzable nitrogen contents in ash/soybean system were 75.5% and 3.3% higher than those in the pure ash plantation. Total phosphorus content decreased after intercropping, while change of available phosphorus showed an increasing trend. Total potassium and available potassium contents in the larch/soybean system were 0.6% and 17.5% higher than those in the pure larch stand. Total potassium and available potassium contents in the ash/soybean system were 56.4% and 21.8% higher than those in the pure ash plantation.

## Conclusion and way forward

Refining and location based dryland farming systems are important in enhancing sustainability in small scale farming systems. They encourage growing of more than one crop in the same space which is helpful in species diversity, ecosystem insect population balances and soil texture-microorganism dynamism. Selection of cover crops and dryland screening of plant genotypes can be used to increase agrobiodiversity and improve microclimate conditions in drylands. These efforts similarly, have been shown to have advantages in enhancing nutrient availability, soil moisture retention, microbial and earthworms activities alongside improved physical soil properties and stability in food security. In some cases intercropping crops that have good combining ability results in increased land use efficiency, water use efficiency. Thus development of farming systems for dryland areas should consider both the long term effects of the ecosystem and the short term benefits of sustaining yields, which in the long term will be useful to the natural resources and food security. It is



always important to consider sole crops of different genotypes that can be grown in the same site to increase yields and enhance agrodiversity.

Research on dryland crops should be broad enough to consider the combinability of different crops under intercropping and sole cropping farming systems (especially the newly developed varieties) for the long term sustainability of agrodiversity and food security which would in turn conserve the environment. Monocropping should be developed in such a way that they include varieties that are suitable for different plots in the same site to enhance diversity. It is also necessary for researchers to consider efficient utilization of underground diversity when developing farming systems such as microorganisms and nutrients. This may be done using modelling approaches that have been tested for different ecosystems. It is also necessary to recognize that farmers continue to intercrop despite recommendation to grow sole crops.

## Acknowledgement

We thank the staff of KARI Katumani for the information shared and the management of South Eastern Kenya University for providing the necessary support to publish this work.

## References

1. Andrews, D.J., and A.H. Kassam. 1976. The importance of multiple cropping in increasing world food supplies. In: *Multiple Cropping*. Special Publication No. 27. Madison, Wisconsin: American Society of Agronomy.
2. Anon. 1995. Regional Research Project Document. National Dryland Research Centre, Katumani.
3. Bakhtri, M.N., Gavotti, S, Odhiambo, S. and Nguluu, S. 1983. Farming Systems Research at NDFRS Katumani. Kenya Dryland Farming Research and development Project, KEN 74/017/; Project Field Document NO.2.
4. CCD Secretariat. 1997. United Nations Convention to Combat Desertification in those countries experiencing serious drought and / or desertification, particularly in Africa. Text with Annexes Geneva.
5. Chang, J.F., and R.M. Shibles. 1985. An analysis of competition between intercropped cowpea and maize. II. The effect of fertilizer and plant population. *Field Crops Research* 12: 145-152.
6. Dalal, R.C. 1974. Effects of intercropping maize with pigeonpea on grain yield and nutrient uptake. *Experimental Agriculture* 10: 219-224.
7. De Jager, A., Van Keulen H., Maina, F. Gachimbi, L.N., Itabari, J.K., Thurania, E.G., and Karuku, A.M. 2005. Attaining Sustainable Farm Management Systems, in Semi-arid areas in Kenya. Few Technical Options, Many policy Challenges. *International Journal of Agricultural Sustainability*. 189-205.
8. Gachimbi, L.N., Van Keulen, E., Thurania, E.G., Karuku, A.M., De Jager, A., Nguluu, S.N., Ikombo B.M., Kinama, J.M., Itabari, J.K., and Nandwa, S.M., 2005. Nutrient balances at farm level in Machakos (Kenya), Using a participatory monitoring approach (NUTMON). *Land policy*, 22:13-22.
9. Government of Kenya 2009. Ministry of Agriculture Food security Report
10. Haylett, D.G., 1960. Run-off and soil erosion studies at Pretoria. *South African Journal of Agricultural Science* 3: 379-394.
11. Hikwa, D., and L. Mukumbira. 1995. Highlights of previous, current, and proposed soil fertility research by the Department of Research and Specialist Services (DRSS) in Zimbabwe. In S.R. Waddington (ed.), Report on the First Meeting of the Network Working Group, Soil Fertility Research Network for Maize-Based Farming Systems in Selected Countries of Southern Africa. Lilongwe, Malawi, and Harare, Zimbabwe: The Rockefeller Foundation Southern Africa Agricultural Sciences Programme and CIMMYT. Pp. 21-33
12. Itabari, J.K., Nguluu, S.N., Gichangi, E.N., Karuku, A. M., Njiru, E.N., Wambua, J.M., Maina, J.N. and Gachimbi, L.N. 2004. Managing Land and Water Resources for Sustainable Crop Production in Dry areas: A case study of small scale farms in semi-arid areas of Eastern, Central and Rift valley provinces of Kenya. In: Criss L. (ed.) *Agricultural Research and Development for Sustainable Resource Management and Food Security in Kenya*. Proceedings of End of Programme Conference, KARI, 11-12 November, 2003. pp. 31-42.
13. Jaetzold, R and Schmidt, H. 1983. *Farm Management Handbook of Kenya Vol. II Natural Conditions and Farmer Management information- part C, Eastern Kenya*.
14. Kaihura F, Stoking, M. (2003). *Agricultural biodiversity in smallholder farmers of East Africa*. United Nations University Press.
15. Keating, B.A. Siambi, M.N. and Wafula, B.M. 1992. The impact of climatic variability on cropping research in semi-arid Kenya between 1955-1985. A search for Strategies for sustainable dryland cropping in semi-arid Eastern Kenya. *ACIAR proceedings* No. 41, 16-25.
16. Kumwenda, J.D.T. 1995. Soybean spatial arrangement in a maize/soybean intercrop in Malawi. Paper presented at the Second African Crop Science Conference for Eastern and Central Africa, 19-24 February 1995, Blantyre, Malawi.



17. Kumwenda, J.D.T., V.H.K. Kabambe, and W.D.M. Sakala. 1993. Maize-soybean and maize-bean intercropping experiments. In *Maize Agronomy Annual Report for 1992/93*. Lilongwe, Malawi: Chitedze Agricultural Research Station.
18. Manna, M.C. and Singh, M.V. 2001. Long term effects of intercropping and biolitter recycling on soil biological activity and fertility. *Bioresource* . 76 (2) :143-150.
19. Manson, S.C., D.E. Leighner, and J.J. Vorst. 1986. Cassava-cowpea and cassava-peanut intercropping. III. Nutrient concentration and removal. *Agronomy Journal* 78: 441-444.
20. Mariga, I.K. 1990. Effect of cowpea planting date and density on the performance of a maize-cowpea intercrop. *Zimbabwe Journal of Agricultural Research* 28: 25-131.
21. McCown, R.L. Keating, B.A. Probert, M.E. and Jones, R.K. 1992. Strategies for sustainable crop production in semi arid Africa. *Outlook on Agriculture* 21, 21-31.
22. Mugagga, F., Buyinza, M. and Kakembo, V. 2010. Livelihood diversification strategies and soil erosion on mountain Elgon, Eastern Uganda: A Socio-economic Perspective. *Environmental Research Journal*, 4, 272 - 280
23. Muhammad , L.M. and Parton, K.A. 1992. Small holder Farming in semi-arid Eastern Kenya. Basic issues relating to modelling of Adoption. In: *Search for Strategies for Sustainable Dryland Cropping in Semi-arid Eastern Kenya*. ACIAR PROCEEDINGS NO.41. 119-123.
24. Mulwa, F.W and Nguluu, S.N. 2003. Participatory Monitoring and Evaluation. A strategy for organization strengthening. Second revised Edition. Zapf chancery and PREMESE Olivex Publishers, Nairobi Kenya.
25. Nadar, H.M. 1984. Intercropping and intercrop component interaction under varying rainfall condition in Eastern Kenya. III. Maize and Pigeon pea intercrop. *E. Afr. Agric. For. J.* 44: 182-188.
26. Natarajan, M., and E.M. Shumba. 1990. Intercropping research in Zimbabwe: Current status and outlook for the future. In: S.R. Waddington, A.F.E. Palmer, and O.T. Edje (eds.), *Research Methods for Cereal/Legume Intercropping*,. Mexico,
27. O'Leary, M. 1984. *The Kitui Akamba*, Heinemann Educational Books.
28. Okalebo, J.R. Simpson, J.R. and Probert, M.E. 1992. Phosphorus status of cropland soils in the semi arid areas of Machakos and Kitui districts, Kenya. In: Probert, M.ed. *A Search for Strategies for Sustainable Dryland Cropping in semi- arid Eastern Kenya*. ACIAR proceedings No. 41, 50-54
29. Okwach, G.E and Simiyu, C.S. Evaluation of long term effects of management of land productivity in a semi-arid area of Kenya using simulation models. *E.Afric. For. J.* 65(2), 143-155
30. Olasantan, F.O., Ezumah, H.C. and Lucas, E.O. 1996. Effects of intercropping with maize on the microenvironment, growth and yield of cassava. *Agriculture Ecosystems and Environment*. 57 (2) : 149-158.
31. Probert, M.E., Okalebo, J.R., Simpson, J.R., and Jones, R.K. 1992. The role of Boma manure for improving soil fertility. In: Probert, M.E. (ed.). *A Search for Strategies for Sustainable dry land cropping in Semi-Arid eastern Kenya*. Proceedings of a Symposium held in Nairobi, Kenya, 10-11 December, 1990. ACIAR Proceedings No. 41, Canberra, Australia.
32. Queeijeiro, G.J.M. 1997. Effect of intercropping with cereals on soil fertility of soils under chestnut culture in North eastern Spain. *Acta. Hort.* 448:283-288.
33. Sakala, W.D.M. 1994. Crop management interventions in traditional maize pigeonpea intercropping systems in Malawi. MSc thesis. Lilongwe, Malawi: Bunda College of Agriculture, University of Malawi.
34. Shumba, E.M., H.H. Dhliwayo, and O.Z. Mukoko. 1990. The potential of maize-cowpea intercropping in low rainfall areas of Zimbabwe. *Zimbabwe Journal of Agricultural Research* 28: 33-38.
35. Simpson, J.R. Karanja, D.R. Ikombo, B.M. and Keating, B.A. 1992. Effects of legumes in a cropping rotation on an infertile soil in Machakos district, Kenya, in: Probert, M.ed. *A Search for Strategies for Sustainable Dryland Cropping in semi- arid Eastern Kenya*. ACIAR proceedings No. 41, 44-49
36. Sijali, I.V., Radiro, M.O. and P.M. 2003. Salt affected soils. Proceedings of a workshop held in Taita Taveta, Kenya on 22-27 August, 2003. IDRP report, Nairobi, Kenya. KARI irrigation and Drainage Programme.
37. Tarhalkar, P.P. and Rao, N.G.P. 1981. Genotype plant density considerations in the development of an efficient intercropping system for sorghum. In: *Proceedings of the International workshop on intercropping*, 10-13 January 1979, Hyderabad, India. Patacheru, A.P. 502324, India. Pp.35-40.
38. Thairu, D.M. and Ariithi, C. C. K. 1987. Intercropping and related agronomic studies 1984-1987. UNDP/FAO Dryland Farming Research and Development-KEN/81/011. Project Field Document No. 8.
39. Tsubo, M., Mukhala, E. Ogindo, H.O. and Walker, S. 2003. Productivity of maize-bean intercropping in a semi-arid region of South Africa. Available on website <http://www.wrc.org.za>



40. van Duivenbooden, N., M. Pala, C. Studer & C.L. Bielders, 2000. Cropping systems and crop complementarity in dryland agriculture: a review. *Netherlands Journal of Agricultural Science* 48: 213-236
41. Willey R, 1979. Intercropping - its importance and research needs. Part 1. Competition and yield advantages. *Field Crop Abstracts* 32: 1-10
42. Zougmore, R., F. Kamboun, K. Ouattara & S. Guillobez, S, 1998. The cropping system of sorghumcowpea in the prevention of runoff and erosion in the Sahel of Burkina Faso. In: D. Buckless, A. Eteka, O. Osiname, M. Galiba & G. Galiano (Eds.), *Cover crops in West Africa: contributing to sustainable agriculture*. International Development Research Centre, Ottawa, pp. 217-224.

