THE EFFECT OF LEGUMES ON NITROGEN DYNAMICS AND PERFORMANCE OF WHEAT (*Triticum aestivum* L.) AND MAIZE (*Zea mays* L.) IN A LEGUME-CEREAL CROPPING SEQUENCE IN THE KENYA HIGHLANDS

Erick Kimutai Cheruiyot

BSc. Agriculture (Egerton University)

Thesis submitted to Graduate School of Egerton University in partial fulfilment of the requirements for the Degree of Master of Science in Crop production

August, 2000.

Declaration

I declare that this thesis is my original work and it has not been previously presented in this or any other University for any degree.

Signature .... **Date** 07.8.2000

Cheruiyot, E.K.

This Thesis has been submitted with our approval as university supervisors

Signed .... **Date** August 7, 2000

Dr. L.M. Mumera

Signed LNakhone **Date** 10/8/2000

Dr. L.N. Nakhone

Signed Mwonga **Date** 8/8/2000

Dr. S.M. Mwonga

Dedication

This work is dedicated to my father Philip who passed away as I was writing this thesis, my mother Ruth, my wife Rose and daughter Clare.

Copyright

Acknowledgements

This work has been made possible through the support and assistance of the following institutions and individuals to whom I am greatly indebted. I do convey my appreciation to Egerton University and the Rockefeller Foundation for supporting my studies and research work respectively. I thank Dr. Mumera, Dr. Nakhone and Dr. Mwonga for their diligent guidance and valuable advise in undertaking this work. The effort by Tatton farm manager, Mr. Sang at Egerton University and that of Mr. Gitau at Rongai to avail research land is sincerely appreciated. My gratitude also goes to Soil Science and Animal Science departments at the University for permission to use their laboratories and equipment in soil and plant tissue analysis. Finally, I sincerely thank my wife, Rose and daughter, Clare for their patience and understanding at the time of undertaking this work.

Table of Contents

List of Abbreviations

C/N	Carbon : Nitrogen ratio
CV	Coefficient of variation
DM	Dry matter
GOK	Government of Kenya
GLP	Grain Legume Project
KARI	Kenya Agricultural Research Institute
MIAC	Mid-America International Agricultural Consortium
N	Nitrogen
P	Phosphorus

List of Tables

List of Figures

Abstract

Wheat (*Triticum aestivum* L.) and Maize (*Zea mays* L.) are the major food crops in Kenya. The country is not self-sufficient in wheat production as it imports over 60% of the local wheat consumption and it barely meets its maize requirement. The bulk of these two cereals are produced in the agricultural high potential Kenya Highlands. However, the level of production currently averaged at 2.0 ton ha^{-1} against a potential of 4.0 and 7.0 ton ha^{-1}for wheat and maize respectively, is low. Among the reasons responsible for the low yields is the declining soil fertility caused by prolonged cereal monoculture. This is exacerbated by the high costs of fertilizers. In an effort to provide remedial solution, biological intervention on soil nitrogen status for improved performance of the cereals was sought through productive management of the short-rains fallow with legumes. Experiments were set up at Egerton University (Njoro) and Rongai, in which five legumes were grown against continuous cereal and traditional weedy fallow during the October-December short-rains and followed by wheat and maize during the April-August long-rains season. The legumes were; chickpea *(Cicer arietinum* L.), field bean (*Phaseolus vulgaris* L.), soybean [*Glycine max*(L.) Merril], garden pea (*Pisum sativum* L.) and dolichos lab lab [*Lablab purpureus* (L) Sweet]. Biomass yield, nodulation, tissue N content, C/N ratio and seed yield were used to evaluate suitability of the legumes as fallow management species. Their effect on soil nitrate status and the response of a succeeding cereal (maize or wheat) test crop in the main season was also determined. Crop growth and development, grain yield and weed population in the succeeding test crop were measured. The traditional fallow provided larger biomass averaged at 2-3.6 ton ha^{-1} against ≤ 2.0 ton ha^{-1} for the legumes with N content below 1.5% and C/N ratio greater than 20. Though legumes produced less biomass, N content was generally above 2% and C/N ratio varied between 10-14 thereby giving better quality residue. Subsequently, improved soil N and performance of the succeeding wheat and maize was observed in the legume-managed plots. Notable observations were that crop biomass, tiller numbers, and spikelets in wheat, and leaf area index, ear numbers, and N-uptake in maize, were improved when the legumes preceded the cereals. Yields increases of up to 36% and 68% in wheat and maize, respectively, were obtained when preceded by legumes against the traditional fallow with outstanding performance in the dolichos-managed fallow. Besides, weed population expansion was restricted in previously legume-managed fallow. Overall, dolichos emerged the most suitable fallow management species.

Chapter One

The status, limitations and potential for improving wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) production in the Kenya Highlands: *A Review*.

1.0 Introduction

1.1 Maize and wheat status in Kenya

Maize (*Zea mays* L.) and wheat (*Triticum aestivum* L.) are the most consumed cereals in Kenya. They are ranked first and second respectively in importance as food crops. Other major food crops include dry beans (*Phaseolus vulgaris* L.), Irish potatoes (*Solanum tuberosum*), sorghum [*Sorghum bicolor* (L.) Moench] and cultivated millet (*Eleusine sp*) (GOK, 1998).

Maize occupies an estimated 1.4 million hectares with annual production of about 2.7 million metric tonnes (KARI, 1992(b); KARI & MIAC, 1993). Statistics indicate fluctuation in annual maize national output over the last eight years ranging from 2.2 to 2.6 million metric tonnes (GOK, 1998). Kenya has remained fairly sufficient in maize grain supply with occasional shortage. Estimates project the country's maize requirement at about 3.67 million metric tonnes by the year 2000, up from 2.48 million metric tonnes in 1990 (Muriuki, 1998). Kenya government projects an annual maize grain production growth at over 4.0% to satisfy the demand (KARI, 1992(b); GOK, 1994).

In the wheat sector, production has increased from 125,900 tonnes in 1992 to some 135,000 tonnes in 1996. Its consumption has risen from 226,700 tonnes to 621,900 tonnes respectively over the same period. Wheat production has therefore increased by only 7% while consumption has accelerated at over 170% during the same period (GOK, 1998). The wheat production and consumption deficit has necessitated the Kenya Government to continuously import 60-70%of annual domestic wheat requirement (GOK, 1998).

1.2. Production inefficiencies and limitations

Available statistics clearly indicate that local cereal production is short of demand (GOK, 1997; KARI 1992(a); KARI & MIAC, 1993) and besides other factors, low maize and wheat yields are important factors that contribute to the shortfall in the national output. The average maize yields in the high potential Kenya Highlands for example is reported as 2.0 tons against a potential of 7.0 tons ha^{-1} giving a yield gap of over 4 tons ha^{-1}. On the other hand, the current average wheat yields of about 2.0 tons ha^{-1} is down below the potential 4 tons ha^{-1} (KARI, 1992(a); KARI & MIAC, 1993).

Despite the use of high yielding quality seed, cereal yields have remained low. The low yields especially in the high potential zones in Kenya is partly attributed to significant decline in soil fertility (KARI, 1992(a); Kinyua *et. al.*, 1989) caused mainly by continuous cereal monoculture. Wheat production in the Kenya Highlands dates back to early 1900 (Hassan *et al.*, 1993) and there is sufficient evidence to demonstrate that continuous cereal monoculture leads to decline in crop yields (Taa *et al.* 1997; Franzluebbers *et al.*,1995; Badaruddin & Meyer, 1994). The situation is aggravated by current upsurge of human population which has risen from 523,000 in 1979 to 849,000 in 1989 reflecting an increase of 60% in this region. This is expected to place high demand on land resource for food cereals.

The above condition has been worsened by increasing cost of inputs especially fertilizers. A 50 kg bag of the popularly used fertilizer (Diammonium phosphate) has risen from US$ 2.3 in 1980 to US$ 6.2 (1990) and US$ 20.3 (1999). The market price of 90 kg bag of maize has risen from US$ 1.2 (1980) to US$ 3.1 (1990) to US$ 10.8 (1999) and the same quantity of wheat from US$ 7.5 (1980) to US$ 5.4 (1990) to US$ 13.5 (1999) (Ministry of Agriculture, 1980; Ministry of Agriculture, 1990). Fertilizer consumption is estimated at 250,000 metric tonnes annually against a projected consumption of one million metric tonnes if all crops are treated as per agronomic recommendation. In addition, estimates indicate that

60% of fertilizer consumed goes to the production of cash crops (mainly tea, coffee and pyrethrum) leaving only 40% for food crops (Muriuki, 1998).

The current practice of cereal monoculture together with rising cost of farm inputs and especially inorganic fertilizer has exacerbated the situation causing cereal yields to fall below the potential. There is an urgent challenge to develop feasible and acceptable cropping systems in this region which not only ensure efficient utilization of cropping area and unit time but also that result in increasing cereal yield. A legume is an ideal choice in such cropping systems for its ability to fix atmospheric nitrogen and the high protein mineralizable organic residue thus immensely enriching soil mineral resource base for companion and succeeding crops. Legumes can fit in with inter-crop, relay and sequential cropping systems with cereals. Studies show a positive shift in physiological response of cereal to soil-N in cereal-legume as opposed to cereal-cereal or cereal-fallow cropping sequence. Decker *et al.* (1987) as cited by Badaruddin and Meyer (1994) reports that N uptake of both fertilized and unfertilized corn following field pea *(Pisum sativum)* was greater than that following barley, wheat or fallow. Badaruddin and Meyer (1994) observed increased N uptake of grain sorghum following soybean as being greater than that of continuous sorghum with or without inorganic-N supply. In addition, nitrogen-use-efficiency for cereal crop following legume has been shown to increase. Badaruddin and Meyer (1994) recorded a 0-32% increase in nitrogen-use-efficiency of wheat following legume compared to that following unimproved fallow and 3-21% greater than for continuous wheat.

Mineral nutrition significantly influences crop yields. Among the three plant primary nutrient elements, Nitrogen (N), Phosphorous (P) and Potassium (K), nitrogen requirement increases most significantly with cropping intensity in wheat (Hassan *et al.* 1993). It is reported that to obtain high maize yields requires heavy N application and its omission results in drastic decline in yield and growth of maize more than any other mineral (Fleming *et al.*, 1981). Commercial farmers constantly endeavour to replenish soil nitrogen reserves with inorganic nitrogen fertilizers in the hope of sustaining cereal yield. However inorganic-N fertilizers are expensive and out of reach for most small scale farmers (Fleming *et al.*, 1981; Reddy *et al.*, 1986; World Bank, 1998). Besides, heavy N application exerts tremendous demand on fossil fuel in its production whose sources have become less dependable and in addition, higher rates of inorganic N pose potential negative impact on the environment particularly the risk of induced low haemoglobin in animals (Stute & Posner, 1993). Sustenance of long-term crop production depend in part on successful resource management that is dynamic in response to human needs. A legume intervention in increasing cereal grain yield with an inverse reduction in inorganic-N fertilizer input has been demonstrated elsewhere (Taa *et al.*,1997). Studies have shown positive benefits on cereal yield in cereal-legume cropping systems. For instance, in Indiana, maize following soybean yielded higher compared to cereal in monoculture with conventional tillage (Franzluebbers *et al.*, 1995). Taa *et al.* (1997) observed that crop response to inorganic-N fertilizer was markedly reduced in a two year cereal-legume rotation and attributed this shift to high soil-N status caused by the rotation sequence.

1.3 Cereal cropping in the Kenya Highlands: The untenability of fallowing

Wheat has been grown in the Kenya Highlands dating back to early 1900 (Hassan *et al.*, 1993). Recent trends indicate an emerging production of maize (*Zea mays* L.) in the region mainly due to influx of human population which has resulted in fragmentation of previously large scale farms into small holder units. Wheat production is traditionally a large scale operation seeded shortly after the onset of the long-rains season which starts in April/May and is harvested in September. Few farmers have attempted to double-crop with either cereal or legume during the short-rains season which occurs between October and December. However majority of farmers fallow the land during this season and wait for the long-rains season in the following year. It has been a traditional practice amongst large scale wheat farmers to light-harrow fields after wheat harvest for purposes of weed control and moisture conservation during the fallow phase. There is little robust data to support this expectation. With the rising demand for cereals in Kenya (Hassan *et al*, 1993; GOK, 1997) and the threat of declining cropping land due to fragmentation of productive land for human settlement (Nyachiro & Briggs 1985; World Bank, 1998) fallowing is no longer tenable.

Studies done elsewhere suggest a great potential for double cropping in wheat growing areas of Eastern Africa (Tanner *et al.*, 1994). The Bale region of Ethiopia for example, has bimodal rainfall pattern, first rains in March-July followed by second rains in August-November. A similar situation to Kenya Highlands is reported from this region where majority of farmers fallow the land between October and February and only a few practise double-cropping. Tanner *et al.* (1994) carried out a study to compare farmers' practice of fallowing and showed that double cropping increased total farm grain output and net income. Thus untapped potential exists on the use of legume as a fallow crop and as an alternative source in soil fertility improvement.

Biological intervention by use of an appropriate legume in a legume-cereal cropping sequence could substantially cut down on inorganic nutrient sources especially inorganic N-fertilizer input in a succeeding cereal crop. The October-December short-rains season which is virtually unutilized poses a great potential for such an intervention. A legume can be grown during this season both as a second crop and as an alternative source for soil quality sustenance. However, the October-December short rains season is characterized by low, erratic and usually unpredictable rains. According to Jaetzold and Schmidt (1983), statistics dating back to 1920s give an average rainfall amount of 250-400mm for the October-December compared to 300-600mm for March-July seasons in the Kenya Highlands. This suggests the need for a suitable legume that not only withstands the local growing conditions but in addition will release sufficient nutrients to the soil upon mineralization of its residue for the benefit of succeeding cereal in the long rains season. A legume that is compatible with the currently under-utilized semi-dry season in the Kenya Highland region could substantially reduce inorganic fertilizer requirement of the succeeding cereal crop. Added advantages include extra income, nutritional gain and improved yield of succeeding cereal crop. Some of these benefits have been reported elsewhere (Ithinji , Personal communication; Guto, 1997; Onwonga, 1997). However these authors did not investigate the possibility of double-cropping during the less utilized semi-dry short-rains season between October and December. They were also limited in number of possible legumes, restricted their study to one site and one season and did not include maize as a test crop yet it is a commonly grown crop in the region. The possibility of double-cropping with a suitable legume during the short-rains season for the benefits stated above in the Kenya Highlands remains under explored. This study focuses on the management of the short-term fallow season between October and December and aims at determining the possible benefits that accrue to the subsequent cereal crop(s).

1.4 Potential short-rains season legumes

1.4.1 Chickpea (*Cicer arietinum* L.)

Chickpea is a native crop of the Mediterranean basin and the Indian sub-continent and is regarded as one of the world's major pulse crops. Its cultivation has spread southward to the Ethiopian and the East African Highlands (Smartt, 1990).

Chickpea is grown for seed which is either cooked and consumed directly or processed into different forms before consumption. In addition, the crop is used as animal feed whose share is estimated at 14% of the total domestic supply in India (Jodha and Rao, 1987). Seed yields ranging from 2.5 to 4 tonnes ha^{-1} and a biomass of between 2.0 and 8 tonnes ha^{-1} have been reported in the Mediterranean and West Asian region (Khanna-Chopra and Sinha, 1987).

The crop is being introduced in Eastern Africa region due to noted adaptability of some genotypes to local growing conditions. It is a legume that is adapted to cool, dry conditions and grows almost exclusively on residual soil moisture (Smithson *et al.* 1985). The legume is adversely affected by excess soil moisture and hot temperature (Saxena and Singh, 1987). This implies that it is grown entirely in post-rainy season and almost frequently on residual soil moisture and hence its probable compatibility with the semi-dry season of the Kenya Highlands. Initial observation indicate that some chickpea genotypes are acclimatized to the growing conditions of the Kenya Highlands (Mwandemele, unpublished data) and the warmer drier regions of Eastern Kenya (Rheenen *et al.*, 1991). However, more detailed characterisation of chickpea performance in this region need to be described.

1.4.2 Dolichos LabLab [*Lablab purpureus* (L) Sweet]

Dolichos Lablab, locally known as *Njahi* is widely cultivated in the tropics particularly in Africa. It is mainly grown for dried seed which can either be cooked and eaten directly or processed to make bean cake. Young pods, leaves and flowers may be eaten as table vegetable. Besides, it is a good forage crop that can be grazed directly by livestock or preserved in the form of hay for animals. In addition, the crop is an excellent green manure, frequently being used in mixed cropping and crop rotation systems as source of nitrogen nutrition for companion or succeeding crops (National Academy of Sciences, 1979; Smartt, 1990).

Dolichos lablab is a deep rooted legume and establishes easily under wide range of conditions. It is adapted to arid, semi-arid and humid regions with an annual precipitation of 200-2500 mm and is drought tolerant once established. It can withstand temperature range of 22-35°C and does well under wide range of soils including soils of low fertility (Smartt, 1990; Skerman *et al.*, 1988 and National Academy of Sciences, 1979). Seed yields ranging from 1.5-4 tonnes ha^{-1} have been reported by the same authors. Dry matter yield widely range from 1,611 to 44,832 kg ha^{-1} with an estimated N content of about 2.24% (Skerman *et al.*, 1988).

1.4.3 Garden pea (*Pisum sativum* L.)

Garden pea is a popular crop of the temperate zones. However, its cultivation has spread to the cooler regions in the tropics. Garden pea is grown for both mature and immature green seed which is cooked and eaten as vegetable. The vegetative parts after seed harvest may be used for silage (Davis *et al.*, 1985; Smartt, 1990).

The crop is adapted to wide range of growing temperature (10-30°C), though it is sensitive to high temperature and moisture stress during flowering, Davis et al. (1985) found that it does well at high elevations in the tropics. Garden pea has been used in a legume-cereal rotation primarily to improve soil nutrient status and cut down on fertilizer requirements by succeeding cereal crop (Fougeroux, *et al.,* 1988). In India for instance, a reduction in N-fertilizer requirement of 20 and 32 kg ha^{-1} for maize compared to wheat or fallow respectively was recorded in plots succeeding garden pea while a reduction by 19-75 kg N ha^{-1} in subsequent cereals after a crop of peas has been reported in United Kingdom. In France, an estimated 50 kg N ha^{-1} was returned to the soil by peas (Davis *et al.*, 1985). The major contribution of N is thought to be derived from mineralizable haulm whose yield is reported as 2.5-3 tons ha^{-1} with 1.6 to 2.67% N.

1.4.4 Field bean (*Phaseolus vulgaris* L.)

Phaseolus vulgaris L., commonly known as field bean, dry bean or common bean is widely grown in Kenya. There is a wide range of cultivars with varied adaptability to the vast agroecozones thereby making field bean a popular and one among the staple food crops in the country. Besides adaptability, market value and farmers' preference influence choice of cultivar. GLP 2 (Rose coco) is a popular cultivar in the Kenya Highlands due to its adaptability and attractive market price (Ronno, 1994). Field bean is mainly produced in a maize-bean inter-crop though production under crop rotation is sometimes practised. The average yield is reported as 700 kg ha^{-1} mainly in inter-crop but the potential is upto 3000 kg ha^{-1} (Gethi and Muriithi, 1993), and it has been evaluated in the previous studies for its contribution to soil fertility replacement in cropping mixtures (Pilbeam *et al.*, 1995).

1.4.5 Soybean [*Glycine max* (L.) Merril]

Soybean is considered the world's most important oilseed and grain legume crop. Its origin is China but cultivation has spread world wide. The crop is grown for seed which has high protein (46%) and vegetable oil (21%). The oil is used for cooking, salad dressing, margarine, frozen dessert and soup among other uses. Flour can be obtained from dry soybean seed which can be baked into bread, used to make soybean milk and/or bean curd. About 98% of soybean residue after oil extraction is fed to livestock as a protein supplement (Hume *et al.*, 1985).

Soybean is grown as a sole crop, relay and sequential crop especially with cereal crop but is rarely inter-cropped. Seed yields ranging from 2.0-3.7 tons ha^{-1} have been recorded. Soybean is also grown as green manure especially as a supplement for N-requirements in cereal crops. Studies indicate that it can supply an equivalent of upto 25 kg N ha^{-1} to a succeeding crop of corn (Carangal, 1986).

1.5 Hypotheses for research

In the light of the above and with determined effort to improve cereal yields in the Kenya Highlands, the following research hypotheses were postulated;

(i) double-cropping in maize and wheat growing areas of the Kenya Highlands is tenable and does increase total farm crop yield, and this yield increase is associated with increases in soil N attributed to the legume,

(ii) different legume genotypes grown in the short-rains season vary in their contribution to soil nitrogen status and this affects the performance of succeeding maize and wheat in a legume-cereal cropping sequence,

(iii) legumes vary considerably in their adaptation to growth and development during the short-rains season fallow of the Kenya Highlands and

(iv) by cultivating the fallow, several weed species are prevented from completing their growth cycles and without seed set, weeds demographic expansion and interference in the subsequent season are restricted.

1.6 Reference

Badaruddin, M. and D.W. Meyer. 1994. Legume effects on soil nitrogen, grain yield and nitrogen nutrition of wheat. Crop Science. 34:1304-1309.

Carangal, V.R. 1986. Soybean in rice-based farming systems: The IRRI experience. In: Soybean In Tropical and Subtropical Cropping Systems. Proceedings of a symposium held in Tsukuba, Japan 26th September - 1st October 1983. The Asian Vegetable Research and Development Centre, Shanhua, Taiwan, China. pp 25-36.

Davies, D.R., G.J. Berry, M.C. Heath and T.C.K. Dawkins. 1985. Pea (*Pisum sativum* L.). In: R.J. Summerfield and E.H. Roberts (eds.). Grain legume crops. Collins, Lond. pp 147-198.

Fleming, A.A., J.E. Giddens and E.R. Beaty. 1981. Corn yields as related to legumes and inorganic nitrogen. Crop Science. 21: 977-980.

Fougeroux, A., J. Desbureaux and C. Girard. 1988. Agronomical effects of spring peas in rotations. In: Legumes in farming systems. Proceedings of a workshop on 'Legumes in Farming Systems' held in Boigneville (France), May 25-27, 1988. Kluwer Academic Publishers, The Netherlands. pp 37-46.

Franzluebbers A.J., F.M Hons and V.A Saladino. 1995. Sorghum, wheat and soybean production as affected by long term crop sequence and N-fertilization. Plant and Soil. 173:55-65.

Gethi, M. and L.M. Muriithi. 1993. Ecological factors affecting the population dynamics of the black bean aphid (*Aphis fabae scopoli*) and their role in the epidemiology of Bean Common Mosaic Virus (BCMV). In: Pan-African working group on bean entomology, Harare, Zimbabwe, 19-22 September, 1993. pp 94-99.

GOK. 1997. Economic Survey. Central Bureau of Statistics, Office of the Vice-President and Ministry of Planning and National Development. Government Printer, Nairobi, Kenya. pp 124-130.

GOK. 1998. Economic Survey. Central Bureau of Statistics, Office of the Vice-President and Ministry of Planning and National Development, Government Printers, Nairobi-Kenya. pp 129-132.

GOK. 1994. Sessional paper No. 2 of 1994 on National Food Policy for Renewed Growth. Government Printers, Nairobi.

Guto, S.N. 1997. Effects of chickpea (*Cicer arietinum* cv. Kaburi) and common beans (*Phaseolus vulgaris* L. cv. Rose coco) on wheat performance and soil fertility in a legume-wheat cropping sequence. MSc thesis, Egerton University, Njoro, Kenya.

Hassan, R.M., W. Mwangi and D. Karanja. 1993. Wheat Supply in Kenya: Production technologies, sources of inefficiency and potential for productivity growth. CIMMYT Economics Working Paper No.93-o2. Mexico,D.F.: CIMMYT. pp 1-4.

Hume, D.J., S. Shanmugasundaram and W.D. Beversdorf. 1985. Soyabean [*Glycine max* (L.) Merrill]. In: R.J. Summerfield and E.H. Roberts (eds.). Grain Legume Crops. Collins, Lond. pp 391-432.

Jaestzold R. and H. Schmidt. 1983. Farm management hand book of Kenya. Vol. II/B Central Kenya. Ministry of Agriculture, Kenya incorporation with German Agricultural Team (GAT) of German Agency of Technical Cooperation (GTZ).

Jodha, N.S. and S.K.V. Rao. 1987. Chickpea: World importance and distribution. In: Saxena, M.C. and K.B. Singh (eds). The Chickpea. The International Centre for Research in the Dry Areas. C.A.B. International, UK. pp 1-10.

KARI. 1992 (a). Annual Report, 1991. Kenya Agricultural, Research Institute, Nairobi, Kenya.

KARI. 1992 (b). Improve and sustain maize production through adoption of known technologies. Information Bulletin, Kenya Agricultural Research Institute, Nairobi, Kenya.

KARI-MIAC. 1993. Strategic plan for Cereals in Kenya (1993-2013). Kenya Agricultural Research Institute, Nairobi, Kenya.

Khanna-Chopra, R. and S.K. Sinha. 1987. Chickpea: Physiological aspects of growth and yield. In: Saxena, M.C. and K.B. Singh (eds). The Chickpea. The International Centre for Research in the Dry Areas. C.A.B. International, UK. pp 163-188.

Kinyua, M.G., J.K. Wanjama, J. Kamwaga and S.N. Mwigi. 1989. Current situation of wheat production in Kenya. Kenya Agricultural Research Institute, Nairobi.

Ministry of Agriculture. 1980. Yields cost-prices 1980. Land and Farm management Division. Government Printers, Nairobi, Kenya.

Ministry of Agriculture. 1990. District farm management guideline, 1990. District Agricultural Officer, Narok District.

Muriuki, E.M. 1998. Report of the ECAMAW working group meeting on soil fertility issues in maize and wheat based system in Eastern and Central Africa. 15-19th November 1998, Mombasa Kenya.

National Academy of Sciences. 1979. Lablab Bean. In: Tropical Legumes: Resources for the Future. Panel on Tropical Legumes, Washington, D.C., USA. pp 59-67.

Nyachiro J.M. and K.G. Briggs. 1985. Research needs for the improvement of wheat yields on high aluminium and/or acidic soils in Kenya. In Regional Wheat Workshop, Njoro, Kenya. Sept. 2-5, 1985. pp 81-92.

Onwonga, R.N. 1997. Effect of chickpea incorporation on soil nutrient status and wheat grain yield in a wheat-chickpea rotation. MSc thesis, Egerton University, Njoro, Kenya.

Pilbeam, C.J., M. Wood and P.G. Mugane. 1995. Nitrogen use in maize-grain legume cropping systems in semi-arid Kenya. Biol. Fertil. Research. 42:123-128

Reddy, K.C., A.R. Soffes and G.M. Prine. 1986. Tropical legumes for green manures. I. Nitrogen production and the effects on succeeding crop yields. Agronomy Journal. 78:5-10.

Rheenen, H.A.V., A. Tullu, A.I.S. Mohamed and P. Omanga. 1991. Growing chickpea in Eastern Africa. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Patancheru, A.P. 504 324, India: ICRISAT.

Ronno, W.K. 1994. Development of dry beans (*Phaseolus vulgaris*) lines adopted to high semi-arid conditions in Kenya. In: Proceedings of a workshop group meeting of bean breeders in the Eastern Africa Region, Kampala, Uganda on 30th May - 2nd June, 1994. pp 44-45.

Saxena, M.C. and K.B. Singh. 1987. Chickpea: Physiological Aspects of growth and yield. In: The Chickpea. The International Centre for Research in the Dry Areas. C.A.B. International, UK. pp 163-190.

Skerman, P.J., D.G. Cameron and F. Riveros. 1988. Tropical forage legumes. FAO plant production and protection services, No.2. Italy, Rome. pp 311-319.

Smartt, J. 1990. Pulses of the classical world. In: Grain Legumes - Evolution and Genetic Resources. Cambridge University Press, Great Britain. pp 176-189.

Smithson, J.B., J.A. Thomson and R.J. Summerfield. 1985. Chickpea (*Cicer arietinum*, L.). In R.J. Summerfield and E.H. Roberts (eds.). Grain Legume Crops. Collins, Lond.

Stute, J.K. and J.L. Posner. 1993. Legume cover crops for grain rotations in Winsconsin. Agronomy Journal. 85:1128-1132.

Taa, A., D.G. Tanner, K. Girma and A. Gorfu. 1997. Grain yield of wheat as affected by cropping sequence and fertilizer application in South Eastern Ethiopia. African Crop Science Journal. 5: 147-159.

Tanner, D.G., Z. Yilma, L. Zewdie and G. Gebru. 1994. Potential for cereal-based double cropping in Bale region of South Eastern Ethiopia. African Crop Science Journal. 2:135-143.

World Bank. 1998. World Development Indicators. Washington D. C., USA.

Chapter Two

Adaptability of some legumes as fallow management species during the short-rains season of the Kenya Highlands

Abstract

Kenya Highland is an agricultural high potential zone mainly for the production of wheat and maize. However, decline in soil fertility attributed to prolonged cereal monoculture has greatly depressed potential yields. Typically, the crops are produced exclusively in the April-August long-rains season and land left fallow during the October-December short-rains season. In an effort to improve wheat and maize yields, a three year study was conducted to evaluate adaptability of five legumes to the traditional short-rains fallow as precursor of the cereals. The objective was to identify a suitably adapted legume whose biomass can be incorporated prior to cropping the cereal for the improvement of soil nitrogen status and crop performance. Their biomass production, nodulation characteristics, residue quality and seed production were observed. Legumes produced low biomass compared to cereal and weedy vegetation in the traditional fallow. Soybean and field bean were among legumes with higher biomass. Despite low biomass, dolichos had good nodulation and better quality residue compared to the other legumes. Although seed yield gain was less consistent with legumes at Rongai, considerably good amount of seed DM in

field bean, chickpea and garden pea were obtained at Njoro with better performance in field bean and chickpea.

2.1 Introduction

Kenya Highlands is an agricultural high potential zone mainly for the production of wheat and maize. It has two rainfall seasons annually known as long-rains and short-rains seasons which occur in April-August and October-December respectively. The long-rains season receives 300-600mm of rainfall against 250-400mm for the October-December short-rains season (Jaetzold and Schmidt, 1983).

Wheat and maize are produced in the long-rains season and majority of farmers fallow their land during the short-rains season. Studies indicate decline in soil fertility in the region (Kinyua *et al.*, 1989) which is partly attributed to cereal monoculture particularly wheat whose production dates back to early 1900 (Hassan *et al.*, 1993). The decline in soil fertility coupled with reduced fertilizer input particularly in the production of food crops has greatly contributed to depressed cereal yields (Muriuki, 1998). Viable and less expensive sources of nutrient replenishment in the improvement of cereal yields is needed. Rotation of legumes with cereals has been shown to improve both soil fertility and yield of succeeding cereals (Taa, *et al.*, 1997; Horst and Hardter, 1994; Tanner *et al.*, 1994; Wortmann *et al.*, 1994; Reddy *et al.*, 1986). With the progressive diversion of agricultural productive land to human settlement (World Bank, 1998), extra reallocation of land for legume-cereal rotation by farmers during the main cropping season is not tenable. However, great potential exists in the productive use of the virtually unutilized semi-dry short-rains season for the production of some suitable legumes to be succeeded by cereals in the long-rains season. Tanner *et al.* (1994) compared farmers' practice of fallowing in one of the two annual seasons in the Bale region of Ethiopia and showed that crop-managed fallow increased total farm grain output and the yield of succeeding cereal was improved when preceded by a legume. Guto (1997) and Onwonga (1997) showed improved grain yield in wheat following field bean (*Phaseolus vulgaris* L.) and chickpea *(Cicer arietinum* L.). However, the two authors conducted their studies at the end of the short-rains season with only two legumes and limited their work to one season at Egerton, Njoro. There is little published information on productive utilization of the traditional October-December fallow gap and therefore its use remains largely unexplored.

Suitably adapted legumes could be used to manage the traditional fallow in the Kenya Highlands and their biomass ploughed under prior to sowing of a cereal in the April-August main cropping season. Such a legume should tolerate heat and moisture stress and produce sufficiently good quality biomass to warrant substantial reduction of fertilizer input in the succeeding cereal. Initial observations indicate that chickpea is adapted to the dry conditions of the Kenya Highlands and Eastern Africa (Mwandemele, unpublished data; Rheenen *et al.*, 1991). Detailed evaluation of this and other local promising legumes on their productivity and influence on succeeding cereals is needed.

In this study, five legumes were evaluated for their adaptability to the short-rain season at Njoro and Rongai both in Nakuru District. The legumes were; chickpea *(Cicer arietinum* L.), field bean (*Phaseolus vulgaris* L.), soybean [*Glycine max*(L.) Merril], garden pea (*Pisum sativum* L.) and dolichos lab lab [*Lablab purpureus* (L) Sweet]. Maize, wheat and weedy fallow were included as controls in the study alongside the legumes. Evaluation centred on biomass production, residue tissue N (%) and C/N ratio, legume nodulation characteristics and seed/grain production alongside site changes in soil water content, rainfall and temperature. It was hypothesised that double-cropping in wheat growing areas of the Kenya Highlands is tenable and does increase farm crop yields and this yield increase is associated with increases in soil N attributed to the legume. Results of this study are discussed in this chapter.

2.2 Materials and Methods

2.2.1 Site description

Two similar experiments were set up at Egerton University, Njoro and Rongai both in Nakuru District in Kenya. The experiments were part of the sequential cropping aimed at evaluating the effect of fallow management practices during the short-rains season on the performance of succeeding maize (*Zea mays* L.) and wheat (*Triticum aestivum* L.) in the long-rains season.

The distance between the two research sites is about 30 km and were selected because of their distinct differences in soils and weather conditions which reflect on crop productivity in the Rift Valley Kenya Highlands. Rongai is at an altitude of 1945m above sea level with mean annual temperature range of 16-18°C and receives an average rainfall of 900 mm annually. The soils are well drained sandy clay loam (Vitric Andosols). Egerton University is at an altitude of 2250 m above sea level and receives annual precipitation of about 1000 mm and has a mean annual temperature range of 14-16°C. The soils are well drained Mollic Andosols (Jaetzold and Schmidt, 1983).

2.2.2 Experimental design and application of treatments

A two factor experiment was set up in Randomized Complete Block Design (RCBD) with 21 treatments arranged in split-plots and replicated three times. These experiments were part of legume-cereal sequential cropping study aimed at determining the influence of legumes on soil NO_3^- level and the performance of succeeding cereal crop. Whole plot treatments were three levels of N-fertilizer (0, 30, and 60 kg ha^{-1}) with the N source being Calcium Ammonium Nitrate (NH_4NO_3 + $CaCO_3$) and were only applied to the succeeding cereal crop. The whole plots measured 4x21 m with 1 m path separating them. The sub-plots measuring 4x3 m were assigned to seven treatments which included five legumes, a cereal (wheat or maize) and traditional fallow, all of which were regarded as fallow-management treatments. The seven sub-plot treatments were applied during the October-December short rains season and were; chickpea *(Cicer arietinum* L.), field bean (*Phaseolus vulgaris* L.), soybean [*Glycine max*(L.) Merril], garden pea (*Pisum sativum* L.), dolichos lab lab [*Lablab purpureus* (L) Sweet], maize or wheat and fallow.

Land preparation was done for all experimental units except for fallow treatment. The land preparation was done between late September and early October followed by sowing in mid October. All the legume seeds were inoculated with their specific strain of *Rhizobia* prior to sowing in the first season only and sown without inoculation in the subsequent seasons. Each crop was sown as per recommended spacing; chickpea 30x10 cm, field bean 50x20 cm, soybean 45x15 cm, garden pea 45x15 cm, dolichos lab lab 60x30 cm and maize 75x30 cm/wheat 20 cm x drill. Inorganic-P was applied uniformly at sowing to all the crops at 60 kg P_2O_5 ha^{-1} with source being Triple Super

Phosphate $Ca(H_2PO_4)_2H_2O$ (TSP) as is recommended for legumes and cereals (KARI, 1997). Inorganic-N was not provided as legumes are capable of fixing enough N for their needs. The cereal control plots did not receive N either during the short-rains. All data were organized and subjected to analysis of variance and mean separation procedures as given elsewhere (Steel et al., 1997; SAS, 1996).

2.2.3 Parameters and sampling procedures

(a) Parameters:

The following indices were used to determine the potential of the treatments as fallow management practices in the region:

(i) Establishment as determined by crop stand count.

(ii) Nodule count and nodule dry weight.

(iii)Vegetative biomass production.

(iv)Vegetative tissue N content.

(v) Seed production.

(vi) Soil water content changes during growing season.

(b) Sampling procedures:

i) Nodule count and their dry weight.

The legumes were inoculated with specific strain of *Rhizobia* only in the first season as stated in the last section (2.2.3). However, as a deliberate attempt to limit input costs during this erratic semi-arid season, inoculation was not done in the subsequent seasons in order to determine the legume potential to fix nitrogen in association with soil resident *Rhizobia*. In resource limited situations as is prevalent for most small scale farmers, legumes that can nodulate freely with the native *Rhizobia* are preferred.

Three legumes in each plot were sampled by consistently picking on the 6th plant from each of the three middle rows in each plot except for fallow and cereal plots. This was done just before crop flowering at 82-84 days after emergence. A strong sharp peg was used to loosen soil around the plants and both hands inserted deep into the soil and the whole plant lifted with soil. The soil was shaken off slowly and all nodules carefully plucked and placed on a sheet of paper. The nodules from the three plants in each plot were counted and put in small envelops for subsequent oven drying. The nodules were dried at 65°C for 48 hours and dry weight determined.

ii) Vegetative plant biomass.

Biomass production accruing from each fallow management system is an important indicator of its potential to provide sufficient residue for subsequent incorporation into the soil. However, the quality of biomass in terms of nutrient content in its tissue is even more crucial. To determine the biomass quality, three plants were randomly sampled as in (i) above in each experimental unit except in fallow plots where a one metre quadrat was used and above ground vegetation taken. The sampling was done to coincide with incipient pod set when the plants are expected to be close to the peak of dry matter accumulation. The plants were dried at 65°C to constant weight and dry weight taken. The dry samples were milled and stored for organic carbon and tissue-N analysis.

iii) Soil moisture changes

The October-December short-rains season is characterized by low and usually erratic rainfall. It is therefore termed as semi-dry period. The changing soil moisture level during the season was monitored by determining soil water content at regular intervals beginning from crop establishment to physiological maturity and the performance of the different legume crops noted. Six soil samples were taken randomly within each experiment every three weeks; starting from four weeks after planting and there after, three weeks interval. Sampling depth was 15-20 cm from the surface and the soil put in pre-weighed moisture cans and closed immediately. The cans were weighed, opened and put in drying oven at 105°C for 24 hours. The weight of wet and dry soil was taken as follows; weight of empty can (w_1),weight of moisture can + fresh soil (w_2) and weight of moisture can + dry soil (w_3). Water content was determined thus; % water content $=[(w_3-w_1)-(w_2-w_1)]/(w_3 \text{ x } 100)$ as given by Gardner (1965).

iv) seed production

Besides biomass production, seed production was determined as the ultimate yield of each of the crops. However, dolichos needed longer time than the season to reach seed production and therefore it was hoed under at vegetative stage together with residues of harvested crops in March during seedbed preparation for next cropping season. Soybean could not form seed due to unfavourable conditions of the season.

Harvesting was done by taking two middle row plants and discarding two plants from each end in each row for the crops that set the seed. The seeds were threshed and taken for further drying before yield determination. Crop residues were left in their respective harvested plots. The remaining plants were likewise harvested but seed was not used for yield determination. When all the physiologically mature legumes (chickpea, field bean and garden pea) and cereals (wheat and maize) were harvested, residues in each plot were incorporated by hand hoeing during land preparation. This was done in March as is common practice in this area in preparation for April planting season.

v) Plant tissue analysis

a.) Total N-analysis

0.3 g of each of the samples in 2.3.(ii) above were weighed into digestion tubes and one tablet of 'Kjeltabs' (containing 3.5 g K_2SO_4 and 400 mg $CuSO_4$ per tablet) and 5 mls of conc. H_2SO_4 were added into each tube. They were digested in Tecator 1015 digestor at 360°C for 2 hours. After cooling, each digest was dissolved in 100 mls distilled water and 10 mls taken for distillation as described by Page *et al.* (1982) and Okalebo *et al.* (1993).

b.) Tissue organic carbon

0.03 g ground plant tissue was weighed into 500 ml conical flask and 10 ml 1M $K_2Cr_2O_7$ solution and 20 ml conc. H_2SO_4 added and swirled gently then left for 30 minutes. After elapse of 30 minutes, 200 mls of distilled water and 10 mls of orthophosphoric acid was added and the solution titrated with 0.2 M ferrous ammonium sulphate. Per cent carbon was determined thus; $\%C = 0.003 \times 0.2(V_b - V_t) \times 100/w$, where V_b is volume of blank titre , V_t volume of sample titre and w is weight of the sample taken. C/N ratio was calculated by dividing per cent carbon with the corresponding per cent N in (a) above. This procedure has been comprehensively described by Okalebo *et al.*, 1993.

2.3 Results

2.3.1 Above-ground biomass

Above-ground biomass gain from the fallow management treatments were high in 1997/98 compared to 1998/99 and 1999/2000 cropping season at the two locations. Notable treatment differences in dry matter (DM) yield were observed within locations and across seasons. Despite lack of clear stable patterns over the observation period, indications are that the weedy fallow had the largest biomass (on average 3.58 and 2.03 Mg ha^{-1} at Rongai and Njoro respectively

whilst dolichos, garden pea and chickpea were among species with least biomass yield (0.9 and 0.77 Mg ha^{-1} for dolichos at Njoro and Rongai respectively).

(i) Njoro

Biomass of weedy vegetation in the fallow treatment was larger than the others in 1997/98 and 1999/2000. In the 1998/99 short-rains cropping season, soybean produced the largest DM yield compared to the other treatments although that was not different from field bean in maize experiment. In general, dolichos and garden pea were among the fallow management treatments with consistently low biomass during the three years of the trial. The other crops had mixed results on biomass as an index (Table 2.1 a). This observation is best typified in the maize experiment.

(ii) Rongai

Above-ground biomass in fallow treatment was significantly higher than other treatments in 1997/98. Except in maize experiment, soybean biomass was higher in 1998/99 though the difference was not much larger than that of chickpea. In 1999/2000, wheat and soybean yielded more biomass in wheat and maize experiments respectively than the rest of the treatments. However weedy vegetation and maize DM yield showed no statistical difference from soybean yield in maize experiment. Dolichos, garden pea and chickpea were among crops with comparatively low biomass yield at Rongai (Table 2.1 b).

Table 2.1; Biomass production (Mg ha^{-1}) by the fallow management treatments during the 1997/98, 1998/99 and 1999/2000 short-rains cropping season in both wheat and maize experiments at (a) Njoro and (b) Rongai.

(a) Njoro

Fallow Management treatments	Above-ground biomass (Mg ha^{-1})						
	Wheat Experiment			**Maize Experiment**			**Average (over the years)**
	1997/98	**1998/99**	**1999/00**	**1997/98**	**1998/99**	**1999/00**	
Chickpea	$1.95^{c\phi}$	1.77^{b}	1.23^{c}	2.11^{cd}	1.40^{b}	1.47^{bc}	**1.66**
Field bean	3.07^{bc}	1.62^{b}	0.78^{c}	3.63^{ab}	1.88^{a}	1.08^{c}	**2.01**
Soybean	4.17^{b}	2.50^{a}	1.31^{c}	2.98^{bc}	2.22^{a}	1.56^{bc}	**2.46**
Garden pea	2.12^{c}	1.37^{bc}	0.98^{c}	1.36^{d}	0.92^{cd}	0.99^{c}	**1.29**
Dolichos lab lab	1.22^{c}	0.87^{c}	0.50^{c}	1.44^{d}	0.57^{d}	0.83^{c}	**0.91**
Wheat	3.97^{b}	1.16^{bc}	2.44^{b}	-	-	-	**2.52**
Maize	-	-	-	4.64^{a}	1.11^{bc}	2.40^{b}	**2.72**
Fallow	7.04^{a}	1.50^{b}	3.62^{a}	4.58^{a}	0.71^{cd}	4.08^{a}	**3.58**

(b) Rongai

Fallow Management treatments	Above-ground biomass (Mg ha^{-1})						
	Wheat Experiment			**Maize Experiment**			**Average (over the years)**
	1997/98	**1998/99**	**1999/00**	**1997/98**	**1998/99**	**1999/00**	
Chickpea	1.36^{c}	1.15^{ab}	0.38^{cd}	1.10^{c}	0.96^{a}	0.46^{b}	**0.90**
Field bean	4.03^{b}	0.2^{b}	0.40^{c}	2.83^{ab}	0.52^{a}	0.45^{b}	**1.41**
Soybean	2.60^{bc}	1.95^{a}	0.43^{bc}	1.84^{bc}	1.10^{a}	0.69^{a}	**1.44**
Garden pea	2.91^{bc}	0.83^{b}	0.33^{cd}	2.05^{bc}	*	0.35^{b}	**1.29**
Dolichos lab lab	1.83^{bc}	0.54^{b}	0.24^{d}	1.19^{c}	0.50^{a}	0.32^{b}	**0.77**
Wheat	2.53^{bc}	0.37^{b}	0.72^{a}	-	-	-	**1.21**
Maize	-	-	-	2.14^{bc}	1.72^{a}	0.49^{ab}	**1.45**
Fallow	6.17^{a}	0.77^{b}	0.56^{b}	3.68^{a}	0.48^{a}	0.51^{ab}	**2.03**

[φ] *Means followed by the same letter in the same column are not significantly different as per Duncan means separation procedure ($\alpha=0.05$)*

[*] *Biomass missing due to crop damage by Guinea fowls*

2.3.2 Legume nodulation and residue tissue quality of the fallow management treatments

During 1997/98 short-rains season which was a wet year, virtually all legumes nodulated, however, garden pea and field bean sustained highest nodule populations in both the wheat and maize experiments and chickpea the least at both locations (Table 2.2). In the same year, the DM of these legume species did not show a consistent pattern.

Responses were markedly different during 1999/2000, a very dry short-rains season, during which only dolichos and soybean were able to generate detectable nodules and nodule biomass (Table 2.3). During that year, soybean and dolichos supported 5.11 and 8.00 nodules at Njoro against 2.0 and 6.7 nodules per plant at Rongai respectively. The other legumes had no nodules at both locations.

All the legume treatments had better quality residue compared to weedy fallow and continuous cereal in terms of nitrogen content and C/N ratio (Table 2.4). The C/N ratio was above 21 for the weedy vegetation in the natural fallow, about 24 and 14 in wheat and maize respectively and between 9 and 14 for the legume species. The N content was less than 1.5 per cent for both weedy fallow and continuous wheat but averaged at about 2.0 to 3.0 for the legumes except soybean which had 1.4 per cent N. Dolichos and garden pea reflected much better residue quality with per cent N averaging about 3.0.

Table 2.2; Root nodulation characteristics of legumes grown during the October-December short-rains season at Njoro and Rongai in 1997/98.

a) Njoro

F-Mgt treatments	Wheat Experiment		Maize Experiment	
	Root	Nodules	Root	Nodules
	Counts	DM wt	Counts	DM wt
	No/plant	gms/plant	No/plant	gms/plant
Chickpea	0.00^{b}	-	1.00^{c}	0.02^{b}
Field bean	25.08^{a}	0.24^{a}	25.64^{b}	0.09^{b}
Soybean	4.33^{b}	0.09^{b}	17.23^{bc}	0.29^{a}
Garden pea	36.38^{a}	0.09^{b}	64.08^{a}	0.06^{b}
Dolichos lab lab	10.48^{b}	0.17^{ab}	13.73^{bc}	0.38^{a}

b) Rongai

F-Mgt treatments	Wheat Experiment		Maize Experiment	
	Root	Nodules	Root	Nodules
	Counts	DM wt	Counts	DM wt
	No/plant	gms/plant	No/plant	gms/plant
Chickpea	0.07^{c}	0.00^{b}	0.45^{c}	0.01^{a}
Field bean	29.29^{a}	0.09^{ab}	10.74^{a}	0.37^{a}
Soybean	9.59^{bc}	0.17^{a}	3.37^{bc}	0.05^{a}
Garden pea	23.30^{a}	0.24^{a}	11.55^{a}	0.19^{a}
Dolichos lab lab	10.78^{b}	0.21^{a}	6.89^{ab}	0.14^{a}

Means followed by the same letter in the same column are not significantly different as per Duncan means separation procedure ($\alpha=0.05$)

Table 2.3; Root nodulation characteristics of legumes grown during the October-December short-rains season at Njoro and Rongai in 1999/2000.

a) Njoro

	Wheat Experiment		Maize Experiment	
	Root Nodules		Root Nodules	
F-Mgt treatments	**Counts**	**DM wt**	**Counts**	**DM wt**
	No/plant	**gms/plant**	**No/plant**	**gms/plant**
Chickpea	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}
Field bean	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}
Soybean	5.11^{ab}	0.01^{a}	5.44^{a}	0.02^{a}
Garden pea	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}
Dolichos lab lab	8.00^{a}	0.02^{a}	4.74^{a}	0.02^{a}

b) Rongai

	Wheat Experiment		Maize Experiment	
	Root Nodules		Root Nodules	
F-Mgt treatments	**Counts**	**DM wt**	**Counts**	**DM wt**
	No/plant	**gms/plant**	**No/plant**	**gms/plant**
Chickpea	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}
Field bean	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}
Soybean	2.00^{b}	0.01^{b}	1.00^{b}	0.01^{b}
Garden pea	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}
Dolichos lab lab	6.70^{a}	0.05^{a}	9.45^{a}	0.05^{a}

Means followed by the same letter in the same column are not significantly different as per Duncan means separation procedure ($\propto=0.05$)

Table 2.4 ; Vegetative tissue N (%) and C/N ratio of soil incorporated residues from the fallow management species in 1997/8.

a) Tissue N (%)

	Njoro		Rongai		
	Wheat Expt.	Maize Expt.	Wheat Expt.	Maize Expt.	Average (over locations)
F-Mgt treatments	← Per	cent N→	← Per	cent N→	
Chickpea	2.22^{ab}	2.20^{abc}	2.04^{b}	2.04^{b}	**2.13**
Field bean	1.82^{ab}	1.83^{abc}	2.27^{b}	1.98^{b}	**1.98**
Soybean	0.99^{b}	0.94^{c}	1.91^{bc}	1.79^{b}	**1.41**
Garden pea	2.30^{ab}	2.28^{ab}	3.72^{a}	3.76^{a}	**3.02**
Dolichos lablab	2.95^{a}	2.79^{a}	3.39^{a}	3.41^{a}	**3.14**
Maize	-	2.02^{abc}	-	1.82^{b}	**1.92**
Wheat	1.43^{b}	-	1.36^{bc}	-	**1.40**
Fallow	1.36^{b}	1.37^{bc}	0.96^{c}	0.94^{c}	**1.16**

(b) C/N ratio for incorporated residues at Rongai

	C/N Ratio	
F-Mgt treatments	**Wheat Expt.**	**Maize Expt.**
	← **C/N**	**ratio** →
Chickpea	12.87^{b}	12.88^{b}
Field bean	11.18^{b}	14.14^{b}
Soybean	14.58^{b}	14.73^{b}
Garden pea	9.04^{b}	11.94^{b}
Dolichos lablab	9.06^{b}	12.25^{b}
Maize	-	14.73^{b}
Wheat	24.16^{a}	-
Fallow	32.49^{a}	21.71^{a}
CV (%)	**28.69**	**24.13**

Means followed by the same letter in the column are not significantly different as per Duncan means separation procedure ($\propto=0.05$)

2.3.3 Soil moisture changes during the short-rains season

Site soil water content was less at Rongai compared to Njoro during the short-rains season (Fig A1.1 and A1.2). This trend closely corresponds to the rainfall received during that period (Fig.A2.1 - A2.3)

2.3.4 Seed and grain yield for the short-rains season crops

Seed dry matter for the fallow management crops varied during the three cropping seasons and between locations. Seed gain in field bean was recorded throughout the three years of the trial at Njoro and except for the 1997/98 short-rains cropping season, chickpea and garden pea seed yields were obtained at the same location (Table 2.5). Maize grain yield was harvested in 1997/98 only. At Rongai, seed harvest in field bean, garden pea, wheat and maize was obtained in 1997/98 season only and soybean in 1997/98 and 1999/2000. In general, field bean and chickpea were associated with larger seed weight over the three seasons mainly at Njoro.

Table 2.5; Seed/grain yield of the short-rains season crops which successfully reached physiological maturity during 1997/98 and 1999/2000 short rain season at Njoro and Rongai.

a) Njoro

	Wheat experiment			Maize experiment		
	Grain/Seed yield (kg ha^{-1})			Grain/Seed yield (kg ha^{-1})		
F-management treatments	**1997/98**	**1998/99**	**1999/00**	**1997/98**	**1998/99**	**1999/00**
Chickpea	Ψ	2003	751	Ψ	1601	1154
Field bean	2520	720	405	2387	843	503
Soybean	nil	nil	nil	nil	nil	nil
Garden pea	★	756	262	★	547	263
Dolichos lab lab	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ
Maize	-	-	-	343.8	nil	nil
Wheat	★	nil	★	-	-	-

b)Rongai

	Wheat experiment			Maize experiment		
	Grain/Seed yield (kg ha^{-1})			Grain/Seed yield (kg ha^{-1})		
F-management treatments	**1997/98**	**1998/99**	**1999/00**	**1997/98**	**1998/99**	**1999/00**
Chickpea	Ψ	1091	nil	Ψ	1860	nil
Field bean	2033	nil	nil	2044	nil	nil
Soybean	505	17	nil	490	20	nil
Garden pea	981	nil	nil	1059	nil	nil
Dolichos lab lab	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ
Maize	-	-	-	1088	nil	nil
Wheat	531	nil	nil	-	-	-

Means followed by the same letter in the column are not significantly different as per Duncan means separation procedure (∝=0.05)

$^{\Psi}$Yield missing due to seed damage by *Heliothis armigera*
★Grain loss to birds
ϕCrop incorporate before harvestable seed reached maturity
nil; crop succumbed to droughty condition

2.4 Discussion

2.4.1 Biomass production of the fallow management treatments

The high biomass in the fallow management treatments during 1997/98 compared to 1998/99 and 1999/2000 short-rains seasons (Table 2.1) is attributed to the relatively high rainfall received during that period (Fig.A2.2). Given ample soil moisture, crops as well as weedy vegetation established and grew rapidly with adequate accumulation of dry matter. However under reduced soil moisture as observed during 1998/99 and 1999/2000 short-rains season, drastic drop in biomass for both crops and weedy vegetation was expected. Reduction in soil moisture and increase in temperature (Figs.2.1, 2.2 and A2.1, A2.2) was probably responsible for the low biomass yield in 1998/99 and 1999/2000 cropping seasons.

Tolerance to the semi-dry short-rains season as measured by DM sustenance during the very dry season varied greatly among the fallow management (Table 2.1). Dolichos showed higher degree of tolerance especially at the drier Rongai conditions. Njoro is cooler than Rongai and moisture loss is expected to be lower under dry and cool compared to the dry and hot Rongai environment (Figs.2.1 and 2.2). Crop survival rate at Njoro was high mainly due to low temperature which ensured higher soil moisture storage (Table A2.1 a and b).

Dolichos persisted through extended dry period primarily due to its deep root system which may penetrate down to 2 m depth (National Academy of Science, 1979). Increased root penetration into the lower soil horizons may have ensured continued uptake of water and mineral ions by the crop despite prolonged dry spell. Similarly, soybean has a root system which has been likened to those of cowpeas [*Vigna unguiculata* (L.) Walpers] and grain sorghum [*Sorghum bicolar* (L) moench] that can extract soil moisture from depths of 1.5-2.0 m (Ashley, 1983; Whigham and Minor, 1978). Though chickpea is reported as being capable of drawing water from 1.2-1.5 m depth, the bulk of water used by the crop comes from the most active root zone which is concentrated in the upper 0.6 m of the soil profile (Saxena, 1984). However, in the event of severe water stress, chickpea roots are less susceptible to collapse due to thickened tissue resulting from activity of the pericambium. In contrast with the above legumes, field bean is the most susceptible to prolonged water stress (Laing *et al.,* 1984). Unlike dolichos, soybean and chickpea, the root system in field bean extends only upto between 0.9-1.0m with 50% of the roots concentrated within the upper 0.3 m depth (Halterlein, 1983; Turner, 1986).

The performance of the above legumes during the October-December growing season mainly hinges on soil moisture levels and their differences in water harvesting abilities which appeared to be conferred by their rooting depths.

Hence, dolichos, soybean and chickpea seem to have greater chance of survival during the semi-dry short-rains season.

2.4.2 Biomass quality and legume nodulation of the fallow management crops

Polyphenol, lignin, nitrogen contents and C/N ratios are known to influence rate of mineralization of organic residues and their concentrations have been used as residue quality indices. Organic residues with low levels of polyphenols, lignin, C/N ratio and high N content are better quality material for they decompose rapidly and release nutrient to soil nutrient pool from where growing plants can utilize (Tian *et al.*, 1994; Fox *et al.*, 1990). Dolichos and garden pea residues were of better quality with respect to N (%) content and C/N ratio. The residue N in dolichos and garden pea was on average 171 and 160 % higher and C/N ratio 60 and 61 % lower respectively compared to the vegetation in the weedy fallow. Nitrogen nutrition in crops is essential for protein synthesis which is incorporated in tissues and any process that ensures adequate supply of N to growing plants will improve quality of the residue. In the presence of a suitable *Rhizobium,* adequate soil moisture and temperature, legumes can fix sufficient N for their requirements and thus improve both crop biomass and quality of the crop residue (Marschner, 1995). The reduced nodulation in legumes during 1999/2000 could therefore be attributed to moisture stress and relatively high temperature (Biederbeck *et al.* 1993). For some legume species, compatible native *Rhizobia* may have been absent from the sites of the study. Dolichos had a higher tissue N because of its capacity to accumulate N in its tissue, this was enhanced by its ability to draw up mineral nutrients particularly N from much lower horizon than the other legumes. Increased nodulation suggests higher N fixation which ultimately contributes to tissue N. In culture experiments, 35 days old soybean deprived of N supply and nodulation had its N content drop to 1.5% down from about 8% under normal nodulation and with N supply (Smartt, 1976) suggesting the importance of nitrogen nutrition in tissue N of crop residues.

2.4.3 Grain and seed yield of the fallow management crops

Except for chickpea, all crops grown during the short-rains season are grown locally mainly during the long-rains season. The recorded seed and grain yield in this study were quite low and nil for some compared to what have been achieved elsewhere. For instance, field bean can produce 2.0-3.0 ton ha^{-1} (Gethi and Muriithi, 1993), soybean 2.0-3.7 ton ha^{-1} (Carangal, 1986), dolichos 1.5-4.0 tons ha^{-1} (Skerman *et al.*, 1988) and chickpea 2.5-4.0 tons ha^{-1} (Khanna-Chopra and Sinha, 1987; Spedding *et al.*, 1981), wheat 2.0 tons ha^{-1} and maize 1.5-2.0 tons ha^{-1} (KARI and MIAC, 1993). The low and/or lack of seed yield of these crops during October-December short-rains season (Table 2.5) may reflect inability to acclimatize to the dominant water and radiation stresses during the semi-dry season. The major limiting factor was reduced soil moisture coupled with increased air temperature both of which subject the crops to water stress. In the unusually wet season in 1997/98 (Fig.A2.1), seed yield in field beans, wheat and maize was relatively high compared to 1998/99 and 1999/2000 seasons. However, during the same year, soybean produced empty pods possibly due to unfavourable weather conditions leading to no grain yield. Soybean yield in the subsequent year was quite low. This was attributed to relatively high temperatures and low soil moisture both of which lead to poor yields probably as a result of direct influence of temperature and moisture on pollination and seed set (Whigham and Minor, 1978; Smartt, 1976).

Compared to the other legumes, garden pea and chickpea are more prone to attack by field pests. In 1997/98 cropping season, *Heliothis armigera* infestation resulted in 100% seed loss in chickpea, while garden pea seed was eaten by birds. Intervention measures were deliberately ignored in order to observe the crop's vulnerability to pest attack and therefore identify species which can be managed with minimum input cost. In the subsequent years 1998/99 and 1999/2000, control of *Heliothis armigera* and birds allowed for yield formation in these species. During these years, grain yields were collected from all legumes except for soybean and dolichos. In terms of grain yield, chickpea and field bean provided the greatest quantities with mean yield of 1300 and 1230 kg ha^{-1} respectively for Njoro and 1470 and 2000 kg ha^{-1} respectively for Rongai. Garden pea had intermediate yield of approximately 500 kg ha^{-1} in Njoro and 1000 kg ha^{-1} in Rongai. The inability for dolichos to set seed is probably explained by growth duration being too short for pheneological transition to reproductive phase. It is not clear why soybean did not seed in Njoro although some seed DM was recorded in Rongai. Photoperiodic effects may have been involved but these were not measured. Generally, poor seed yield in 1999/2000 particularly in Rongai was due to a prohibitive drought.

2.5 Reference

Ashley, D.A. 1983. Soybean. In: I.D. Teare and M.M. Peet (eds.) Crop-Water Relations. John Wiley and Sons. pp389-422.

Bieberbeck, V.O., O.T. Bouman, J.Looman, A.E. Slinkard, L.D. Bailey, W.A. Rice and H.H. Janzen. 1993. Productivity of four annual legumes as green manure in dryland cropping systems. Agronomy Journal 85:1035-1043.

Carangal, V.R. 1986. Soybean in rice-based farming systems: The IRRI experience. In: Soybean in Tropical and Subtropical Cropping Systems. Proceedings of a symposium held in Tsukuba, Japan 26th September - 1st October 1983. The Asian Vegetable Research and Development Centre, Shanhua, Taiwan, China. pp 25-36.

Fox, R.H., R.J.K. Myers and I. Vallis. 1990. The nitrogen mineralization rate of legume residues in soil as influenced by their polypheneol, lignin, and nitrogen content. Plant and Soil 129: 251-259.

Gardner, H.W. 1965. Water content. In: C.A. Black (ed.) Methods of Soil Analysis Part 1. American Society of Agronomy, Madison, USA. pp 82-125.

Gethi, M. and L.M. Muriithi. 1993. Ecological factors affecting the population dynamics of the black bean aphid (*Aphis fabae scopoli*) and their role in the epidemiology of Bean Common Mosaic Virus (BCMV). In: Pan-African working group on bean entomology, Harare, Zimbabwe, 19-22 September, 1993. pp 94-99.

Guto, S.N. 1997. Effects of chickpea (*Cicer arietinum* cv. Kaburi) and common beans (*Phaseolus vulgaris* L. cv. Rose coco) on wheat performance and soil fertility in a legume-wheat cropping sequence. MSc thesis, Egerton University, Njoro, Kenya.

Halterlein, A.J. 1983. Bean In: I.D. Taere and M.M. Peet (eds.) Crop-Water relations. John Wiley and Sons. pp 157-185.

Hassan, R.M., W. Mwangi and D. Karanja. 1993. Wheat Supply in Kenya: Production Technologies, Sources of Inefficiency and Potential for Productivity Growth. CIMMYT Economics Working Paper No.93-02. Mexico, D.F.: CIMMYT. pp 1-4.

Horst, W.J. and R. Hardter. 1994. Rotation of maize with cowpea improves yield and nutrient use of maize compared to maize monocropping in an alfisol in the northern Guinea savanna of Ghana. Plant and Soil. 160: 171-184.

Jaestzold, R. and H. Schmidt. 1983. Farm management hand book of Kenya. Vol. II/B Central Kenya. Ministry of Agriculture, Kenya in Cooperation with German Agricultural Team (GAT) of German Agency of Technical Cooperation (GTZ).

KARI. 1997. Crop production guidelines for wheat, oilcrops and horticulture. Arama, P.F., J.K. Wanjama, F. Kiriswa and P.K. Macharia. (eds). National Plant Breeding Research Centre, Njoro.

KARI-MIAC. 1993. Strategic plan for Cereals in Kenya (1993-2013). Kenya Agricultural Research Institute, Nairobi, Kenya.

Khanna-Chopra, R. and S.K. Sinha. 1987. Chickpea: Physiological aspects of growth and yield. In: Saxena, M.C. and K.B. Singh (eds). The Chickpea. The International Centre for Research in the Dry Areas. C.A.B. International, UK. pp 163-188.

Kinyua, M.G., J.K. Wanjama, J. Kamwaga and S.N. Mwigi. 1989. Current situation of wheat production in Kenya. Kenya Agricultural Research Institute, Nairobi, Kenya.

Laing, D.R., P.G. Jones and J.H.C. Davis. 1984. Common bean (*Phaseolus vulgaris* L.). In: P.R. Goldsworthy and N.M. Fisher (eds.) The Physiology of Tropical Field Crops. John Wiley and Sons Ltd. pp 305-351.

Marschner, H. 1995. Mineral nutrition of higher plants. Academic Press, London.

Muriuki, E.M. 1998. Report of the ECAMAW working group meeting on soil fertility issues in maize and wheat based system in Eastern and Central Africa. 15-19th November 1998, Mombasa Kenya.

National Academy of Sciences. 1979. Lablab Bean. In: Tropical Legumes: Resources for the Future. Panel on Tropical Legumes, Washington, D.C., USA. pp 59-67.

Okalebo, J.R., K.W. Gathua and P.L. Woomer. 1993. Laboratory Methods of Soil and Plant Analysis: A working manual. Tropical Soil Biology and Fertility Programme. Nairobi, Kenya.

Onwonga, R.N. 1997. Effect of chickpea incorporation on soil nutrient status and wheat grain yield in a wheat-chickpea rotation. MSc thesis, Egerton University, Njoro, Kenya.

Page, A.L., R.H. Miller and D.R. Keeney. 1982. Methods of Soil analysis Part 2; Chemical and microbiological properties. American Society of Agronomy, Madison, USA.

Reddy, K.C., A.R. Soffes and G.M. Prine. 1986. Tropical legumes for green manures. I. Nitrogen production and the effects on succeeding crop yields. Agronomy Journal. 78:5-10.

Rheenen, H.A.V., A. Tullu, A.I.S. Mohamed and P. Omanga. 1991. Growing chickpea in Eastern Africa. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Patancheru, A.P. 504 324, India: ICRISAT.

SAS institute. 1996. SAS for windows 6.12. Cary NC USA.

Saxena, N.P. 1984. Chickpea. In: P.R. Goldsworthy and N.M. Fisher (eds.) The Physiology of Tropical Field Crops. John Wiley and Sons Ltd. pp 419-452.

Skerman, P.J., D.G. Cameron and F. Riveros. 1988. Tropical forage legumes. FAO plant production and protection services, No.2. Italy, Rome. pp 311-319.

Smart, J. 1976. Mineral nutrition and productivity. In: Tropical pulses. Longman Group Ltd. pp 151-171.

Spedding, C.R.W., J.M. Walsingham and A.M. Hoxey. 1981. Pulse crops. In: Biological Efficiency in Agriculture. Academic press (London) Ltd.

Steel, R.G.D., J.H. Torrie and D. A. Dickey. 1997. Principles and practices of statistics, a biometrical approach. McGraw-Hill Companies, Inc.

Taa, A., D.G. Tanner, K. Girma and A. Gorfu. 1997. Grain yield of wheat as affected by cropping sequence and fertilizer application in South Eastern Ethiopia. African Crop Science Journal. 5: 147-159.

Tanner, D.G, Z. Yilma, L. Zewdie and G. Gebru. 1994. Potential for cereal-based double cropping in Bale region of Southeastern Ethiopia. African Crop Science Journal. 2:135-143.

Tian, G., B.T. Kang and L. Brussaard. 1994. Mulching effect of plant residues with chemically contrasting compositions on maize growth and nutrients accumulation. IITA Research No.9: 7-11.

Turner N.C. 1986. Adaptation of plants to water deficits. Australian Journal of Plant Physiology. 13:175-190.

Wortmann, C.S., M. Isabirye and S. Musa. 1994. *Crotalaria ochroleuca* as a green manure crop in Uganda. African Crop Science Journal. 2: 55-61.

Whigham, D.K. and H.C. Minor. 1978. Agronomic characteristics and environmental stress. In: A.G. Norman (ed.) Soybean Physiology, Agronomy and Utilization. Academic press Inc. pp 77-116.

World Bank. 1998. World Development Indicators. Washington D. C., USA.

Chapter Three

Effect of Selected Grain Legumes on Nitrogen Dynamics and the Performance of Wheat (*Triticum aestivum* L.) in a Legume-Wheat Cropping Sequence in The Kenya Highlands

Abstract

Wheat (*Triticum aestivum* L.) is an important food crop in Kenya with a consumption of 600,000 tons well in excess of a production of about 200,000 tons annually. Insufficient production has forced the Kenya government to import about 60% of local wheat consumption annually. Soil fertility has been cited as a contributing factor to the low yields currently averaged at 1.7-2.0 tons ha^{-1} against a potential of 4.0 ton ha^{-1}. Wheat is traditionally grown during the long-rains season and land left fallow in the short-rains season. An experiment was set up at Egerton University, Njoro and Rongai both within the Kenya Highlands to investigate the contribution of five legumes grown during the short-rains season against a continuous wheat and traditional fallow on soil nitrogen status and response of succeeding wheat in the long-rains season. The impact of improved fallow management practices on weed biomass and species distribution was also assessed during early growth stages in wheat. The legumes were chickpea *(Cicer arietinum* L.), field bean (*Phaseolus vulgaris* L.), soybean [*Glycine max*(L.) Merril], garden pea (*Pisum sativum* L.), dolichos lab lab

[*Lablab purpureus* (L) Sweet]. Crop residues were incorporated prior to seeding wheat and soil sampled for N analysis eight weeks after the incorporation. Wheat biomass, days to heading, tiller count, spikelets numbers, seed weight, grain yield and total grain-N and vegetative tissue-N were determined. Wheat succeeding short rains season crop gave 1.6-2.7 tons ha^{-1} against a preceding fallow with 1.5-2.1 tons ha^{-1}. Improved yields were recorded in wheat following legumes where a corresponding increase in soil N was observed. Higher tiller count, spikelet numbers, grain-N, grain yield and delayed heading, was observed in wheat succeeding legumes generally and more significantly with dolichos. Besides, reduced weed biomass and species were observed in legume-managed fallow. Hence the growth of legumes particularly dolichos, during the short-rains fallow can improve soil N status and the yield of succeeding wheat in the Kenya Highlands.

3.1 Introduction

Wheat is ranked second to maize (*Zea mays* L.) in importance as a food crop in Kenya. Its consumption is estimated at 600,000 tons against production output of 200,000 tons forcing the country to import about 60% of local consumption annually (GOK, 1998; Kinyua , Personal comm).

The bulk of the crop is produced in agriculturally high potential zones in the Kenya Highlands with major producing districts being Nakuru, Uasin Gishu, Trans Nzoia and Narok. These areas lie within 1800-3000m above sea level and receive bimodal rainfall in April-August and October-December locally known as long and short-rains respectively. Wheat is traditionally seeded shortly after onset of the long-rain season and harvested in September. Majority of the farmers fallow their land during the October-December short-rains season. During this period many large scale farmers light harrow their fields once to incorporate straw and induce weeds to germinate and serve as grazing for livestock. The short-rains season receives low and usually unpredictable rains ranging between 250-300mm against 300-600mm in the long-rains season (Jaetzold and Schmidt, 1983).

Wheat has been produced under monoculture for almost a century in the Kenya Highlands (Hassan *et al.*, 1993). Despite genetically improved seed, wheat yields average about 1.7-2 tons ha^{-1} which is far below a potential of 4 tons ha^{-1} in the region (KARI, 1992; KARI & MIAC ,1993; Kinyua, Personal comm.). The low yields are partly attributed to declining soil fertility (Kinyua *et al.*, 1989) which is further exacerbated by reduced input of inorganic fertilizer in the production of food crops in Kenya mainly due to rising costs (Muriuki, 1998). Autotoxicity from allelochemicals may also be a factor in wheat-wheat sequential. A less expensive technology for the improvement of wheat yields is most desirable. The use of a legume in crop rotation has been widely demonstrated as a viable alternative which leads to improved yields of succeeding crops (Taa *et al.*, 1997; Franzluebbers *et al*, 1995; Badaruddin and Meyer, 1994; Wortmann *et al.*, 1994; Reddy *et al.*, 1986). The yield increase in cereal succeeding a legume is attributed to improvement in soil N status.

The October-December fallow gap in the Kenya Highlands can be managed with suitably adapted legumes as a means of improving yield of succeeding wheat. Studies done in the Eastern African region suggest great potential in the productive use of traditional fallow breaks to improve yields of succeeding cereals. In Bale region of Ethiopia for instance, Tanner *et al.* (1994) compared farmers' practice of fallowing land during one of the two annual cropping seasons with double cropping and observed improved grain yield in wheat preceded by field pea (*Pisum arvense* L.). Besides, Crop rotation, inter-crops and cover crops have been shown to reduce or suppress weed incidence in cropland (Altieri and Liebman, 1986; Mloza-Banda, 1997; Mwaja and Masiunas, 1997) though in East Africa, little attention has been given to the impact of legumes on weed infestation in such a cropping system. In their study at Egerton, Guto (1997) and Onwonga (1997) reported positive yield response in wheat succeeding field bean and chickpea. However, their precursor legumes were grown in January, after the short-rains season and closer to when farmers prepare their land for sowing in the April-August main cropping season. They limited the number of possible legumes to two with wheat as the only test crop and restricted their study to one season at Egerton. The semi-dry short-rains season in the Kenya Highlands thus remains largely unexplored as a means of improving yields of succeeding crops particularly the popularly grown cereals.

This study focused on seven management options for the short-rains fallow which included five legume species, a continuous wheat and a traditional fallow in a bid to improve soil fertility and wheat yields. The legumes in the study were chickpea *(Cicer arietinum* L.), field bean (*Phaseolus vulgaris* L.), soybean [*Glycine max*(L.) Merril], garden pea (*Pisum sativum* L.), dolichos lab lab [*Lablab purpureus* (L) Sweet]. Crop residues including weed vegetation in the traditional fallow were incorporated in the soil during seedbed preparation prior to seeding wheat at the onset of long-rains season. The study was conducted to test three hypotheses: that growing of legumes during the short-rains season in the Kenya Highlands increases grain yield of succeeding wheat and that yield increase is associated with improved soil N attributed to the legumes; that different legume genotypes differ in their contribution to soil N and this variation leads to differences in the performance of succeeding wheat in the legume-wheat cropping sequence; and that a competitive challenge by managed fallow would check the growth of weeds and hence reduce their inteference potential in the succeeding cereal crop. The effect of the fallow management systems on soil nitrate status and response of succeeding wheat crop was observed and results are discussed in this chapter.

3.2 Materials and Method

3.2.1 Site description

Two similar experiments were set up in two different sites in Nakuru District in the Rift Valley Province. The sites were Egerton university farm in Njoro Division and a selected farmer's field in Rongai Division, both situated in high potential zone of the Kenya Highlands.

The selected sites had distinct differences in soil and agro-ecozones inspite of the close spartial proximity, a feature that is characteristic of the Kenya Highlands. Egerton University is at an altitude of 2250 metres above sea level and receives 1000 mm of rainfall annually. Its mean annual temperature range is 14-16°C and the soils are well drained Mollic Andosols. Rongai is at an altitude of 1945 metres above sea level and receives slightly less rainfall compared to Njoro of about 900 mm with a mean annual temperature range of 16-18°C. The Rongai soil is a well drained sandy clay loam and is classified as Vitric Andosols. The sites fall within agroecological zone III-6 and III-5 respectively (Jaetzold and Schmidt, 1983).

3.2.2 Experimental design and treatments

A two factor experiment was set up in Randomized Complete Block Design (RCBD) with 21 treatments arranged in split-plots and replicated 3 times. Main plot treatments were three levels of N-fertilizer (0, 30, and 60 kg ha^{-1}) with source being Calcium Ammonium Nitrate ($NH_4NO_3 + CaCO_3$). The N-fertilizer rates were applied to wheat as topdress at tillering growth stage during the long-rains season occurring between April and August. The main plots measured 4x21 m with 1 m path separating them. The sub-plots measuring 4x3 m were assigned to seven treatments representing the alternative approaches to managing fallow during the short-rains season between October- December. The seven treatments were regarded as fallow-management practices (F-mgt) and included; chickpea *(Cicer arietinum* L.), field bean (*Phaseolus vulgaris* L.), soybean [*Glycine max*(L.) Merril], garden pea (*Pisum sativum* L.), dolichos lab lab [*Lablab purpureus* (L) Sweet], wheat and fallow. The fallow-management practices were applied in October and ran through to February of the succeeding year and followed by wheat in April. In October 1997 and 1998, tillage of seedbed by hand hoe was done for all except where fallow treatment was to be applied. Sowing of the crops was done on 17rth and 25th October in 1997, 27st and 31st October in 1998 for Njoro and Rongai sites respectively. Each of the crops was sown at the recommended spacing: chickpea 30x10 cm, field bean 50x20 cm, soybean 45x15 cm, garden pea 45x15 cm, dolichos lab lab 60x30 cm and wheat (var. K. Kwale) 20 cm x drill. Inorganic-P was applied at 60 kg P_2O_5

ha^{-1} at sowing for each of the crops with source being Triple Super Phosphate (TSP) (KARI, 1997).

3.2.3 Harvesting of fallow management crops and residue incorporation

The fallow management crops which formed grain and reached physiological maturity before February were harvested and seed taken. Depending on location and season, crops which formed seed within the fallow period varied but chickpea, field bean and garden pea were consistent. The rest of the crop residues were left in their respective plots. Most of the crops were harvested in January and February of the succeeding year. All crop residues and crops which did not seed or those which did not attain physiological maturity within the season together with the vegetation in the fallow plots were incorporated into the soil in March by hand hoeing during seedbed preparation in readiness for sowing wheat in April.

The effect of the sub-plot treatments on soil N was observed on the performance of succeeding wheat as cereal 'test crop' in the local main season. The test crop was sown at onset of rains in April, exactly four weeks after residue incorporation. The timing was to ensure that optimum residue mineralization projected to occur between 6-8 weeks after incorporation (Palm, 1995;

Handayonto *et al.*, 1992) coincides with linear wheat growth phase which is usually attained four weeks after sowing under normal conditions. The wheat was harvested in September. All cultural practices as pertains to the growing of both fallow management and test crops were followed and differences observed were largely due to treatments.

3.2.4 Sampling and Chemical analysis

(i) Sampling

To determine the contribution of the fallow management treatment to soil-N, the legume nodulation capacity and above-ground biomass production was determined (see section 2.2.3). Three legume plants in each plot were sampled at 50% flowering. In wheat and the fallow plots, a quadrat measuring 1m^2 was thrown at the middle of the plot and all above ground biomass harvested. Each sample in each plot was put in a paper bag and taken for drying in the oven at 65°C until constant dry weight was determined. This was expressed in Mg ha^{-1}. The same samples were ground to pass through a 2 mm sieve and stored for total N determination.

Effect of fallow management systems on soil N status was determined by sampling and analysing fresh soil for available N (NO_3^- + NH_4^+) from a succeeding wheat crop four weeks after sowing. Two soil samples each at 0-15 cm and 15-30 cm depths were taken in each plot and separately put in small marked polythene bags. The soils were then incubated at low temperatures in a fridge pending chemical analysis which was done within two months.

Sampling for weed biomass and assessment of weed species distribution was done at 6th leaf stage in wheat just before herbicide application. In this study, a metre square (m^2) quadrat was thrown in the middle of each plot and weed species within the quadrat identified, counted and recorded. Above-ground biomass of all weeds within the quadrat were taken and put in a paper bag for subsequent oven drying. The weeds were dried at 65°C to constant weight and dry weight determined. The total weed count in each plot was used to calculate species density and their relative per centage. After the sampling, the plots were subjected to regular weed management practices. Wheat was sprayed once with Buctril MC® (bromoxynil and iso-octyl esters) at 1.25 litres ha^{-1} (KARI, 1997) and followed by hand pulling of stubborn and volunteer weeds. Because of this conformity effect, the impact of weeds on the test crop yields was not directly assessed. The data presented focused on responses in 1999 to allow for cumulative effect of fallow management practices in the previous two short-rains seasons.

The above-ground biomass of the test-crop was determined at tillering stage, six weeks after sowing. This was done prior to N treatment application `to measure the effect of fallow management treatments on biomass accumulation in wheat crop at initial growth stages. The above ground biomass was taken from the centre 1m length in two of the fifteen rows in each plot. The third rows from either side of each plot were systematically picked and all above-ground biomass removed from the centre 1 metre length by cutting with a secateur and samples dried at 65°C until constant weight was attained. Their weights were determined and expressed in Mg ha^{-1}. The second and third samplings were done at heading and physiological maturity as above, but picking on 4th and 5th rows respectively.

Harvesting was done at a week after physiological maturity to ensure all the spikes were sufficiently dry for harvesting. Five middle rows in each plot were harvested leaving five rows on either side and 0.5 m length on either end of each harvested row as guard materials. The crop was harvested by cutting the spikes at the peduncle using secateur and putting the spikes in a labelled paper bag for each plot. The spikes from each plot were fed into a potable thresher, winnowed and the grains sun dried to a moisture content of 14%. Grain weight was determined and expressed in tonnes ha^{-1}.

(ii) Chemical laboratory analysis

a) Total N

0.3 g of oven-dried (65°C) ground plant tissue (2mm) was taken in a dry clean digestion tube. 10 mls of conc. H_2SO_4 and one tablet containing lithium sulphate and selenium were added and the contents digested at 360°C for 2 hours. The digest was left to cool then dissolved in distilled water and made upto 50 ml before being allowed to settle. Total N was then determined by distillation and titration as given by Page *et al.* (1982) and modified by Okalebo *et al.*,(1993).

b) Soil available N

8 g of fresh soil was taken in 100 ml plastic bottle, extracted with 80 mls of 2M KCl and contents shaken in mechanical shaker for one hour. After settling, 10 mls of clear aliquot was taken in a distillation tube and about 0.2 g MgO and 0.2 g Devarda's alloy added. The contents were distilled for three minutes using automatic kjedhald distiller. Both NO_3-N and NH_4-N were collected over 5 mls fresh boric acid indicator and titrated with 0.002N H_2SO_4 (Page *et al.*, 1982; Okalebo *et al.*, 1993).

c) Organic carbon

0.03 g ground plant tissue was weighed into 500 ml conical flask and 10 ml 1M $K_2Cr_2O_7$ solution and 20 ml conc. H_2SO_4 was added and swirled gently then left for 30 minutes. After elapse of 30 minutes, 200 mls of distilled water and 10 mls of orthophosphoric acid was added and the solution titrated with 0.2 M ferrous ammonium sulphate. Per cent carbon was determined thus; $\%C=0.003 \times 0.2(V_b-V_t) \times 100/w$, where V_b is volume of blank titre , V_t volume of sample titre and w is weight of the sample taken. C/N ratio was calculated by dividing per cent carbon with the corresponding per cent N in (a) above. This procedure has been described by Okalebo *et al.*, 1993.

All the dependent variable data were computer processed; analysis of variance and separation of means of the same was done following the procedures outlined elsewhere (Steel *et al.*, 1997; SAS, 1996).

3.3 Results

3.3.1 Influence of short-rains season managed fallow on soil N for a succeeding wheat crop

Except for the 1998 cropping season at Rongai, soil available N was statistically higher ($\propto = 5\%$) in plots previously under dolichos compared to preceding wheat and fallow (Table 3.1). Besides, there were noticeable differences amongst legume species on soil N status. Soil available N was higher following dolichos than in a preceding chickpea, field bean and fallow by between 17 and 28% in the 0-15 cm depth at Njoro (1999). There was no statistical difference in the soil N between plots succeeding dolichos and those following garden pea and soybeans.Also, at 15-30 cm sampling depth at Njoro (1999), soil available N in dolichos-managed fallow was significantly greater by 25-44% than the other fallow management treatments. The results were less marked at Rongai, but even under this environment, the soil available N levels, though insignificant were highest in dolichos treatments.

Table 3.1; Effect of fallow management treatments on soil available-N eight weeks after residue incorporation taken at 6th leaf stage in wheat.

	Njoro		Rongai			
	1999		1998		1999	
	Soil available N (μg N/g soil)		Soil available N (μg N/g soil)			
F-Management treatments	← sampling depth →		← sampling depth →			
	0-15cm	**15-30cm**	**0-15cm**	**15-30cm**	**0-15cm**	**15-30cm**
Chickpea	365.3^{b}	295.5^{b}	58.3^{a}	78.5^{a}	282.5^{a}	268.7^{ab}
Field bean	365.2^{b}	341.7^{b}	76.8^{a}	97.9^{a}	408.5^{a}	342.7^{ab}
Soybean	450.1^{ab}	395.4^{b}	63.5^{a}	62.0^{a}	315.4^{a}	325.9^{ab}
Garden pea	449.8^{ab}	335.9^{b}	59.7^{a}	81.2^{a}	360.8^{a}	278.1^{ab}
Dolichos lab lab	506.0^{a}	526.6^{a}	102.1^{a}	102.5^{a}	401.9^{a}	367.2^{a}
Wheat	375.3^{b}	330.0^{b}	90.5^{a}	99.5^{a}	269.6^{a}	287.1^{ab}
Fallow	417.7^{b}	325.9^{b}	78.7^{a}	82.0^{a}	279.8^{a}	225.0^{b}
CV (%)	20.3	26.9	59.3	53.9	52.4	39.2

Means followed by the same letter in the column are not significantly different as per Duncan means separation procedure ($\propto=0.05$)

Soil available N for 1998 at Njoro was avoided due to cost in analysis

3.3.2 Influence of short-rains legume-managed fallow on biomass production and phenological development in succeeding wheat

The effect of fallow management treatments on above ground wheat biomass at seedling stage was less obvious. In general, all legume fallow treatments supported larger wheat biomass (averaging 2.14 against 1.22 Mg ha^{-1} for unimproved fallow in 1998 at Njoro and 0.50 compared to 0.31 Mg ha^{-1} for unmanaged fallow at Rongai for that year), but these differences were less pronounced in 1999 which was unusually drier year. In particular, wheat following dolichos yielded higher biomass compared to wheat succeeding traditional fallow (Table 3.2). The positive influence of dolichos was further observed at early reproductive phase in wheat where larger DM yield was recorded for wheat in sequence with dolichos against low yield for wheat following fallow, wheat and chickpea (Table 3.3). Wheat biomass in response to N application was unspectacular, except at Rongai where both 30 and 60 kg N ha^{-1} gave higher yield than zero N level. The above-ground biomass yields were generally larger for Njoro than Rongai at the two wheat growth stages.

There were also observed differences in treatment effects on phenological changes. The vegetative growth phase was shorter for wheat following weedy fallow compared to wheat after a legume-managed fallow. Wheat succeeding the weedy fallow headed 10-13 days earlier than wheat succeeding a short-rains season crop for Rongai and 4-5 days earlier for Njoro (Table 3.4).

Table 3.2; Effect of fallow management treatments on above-ground wheat biomass at 6th leaf stage as expressed in dry matter weight (Mg ha^{-1}).

F-Management Treatments	Njoro Wheat biomass DM yield (Mg ha^{-1}) 1998	Njoro Wheat biomass DM yield (Mg ha^{-1}) 1999	Rongai Wheat biomass DM yield (Mg ha^{-1}) 1998	Rongai Wheat biomass DM yield (Mg ha^{-1}) 1999
Chickpea	1.92^{ab}	0.31^{ab}	0.46^{ab}	0.34^{a}
Field bean	1.84^{ab}	0.34^{ab}	0.47^{ab}	0.35^{a}
Soybean	1.76^{ab}	0.29^{ab}	0.55^{ab}	0.35^{a}
Garden pea	2.62^{a}	0.29^{ab}	0.44^{ab}	0.29^{a}
Dolichos lab lab	2.58^{a}	0.40^{a}	0.60^{a}	0.31^{a}
Wheat	1.48^{b}	0.35^{ab}	0.47^{ab}	0.32^{a}
Fallow	1.27^{b}	0.25^{b}	0.31^{b}	0.36^{a}

Means followed by the same letter in the column are not significantly different as per Duncan means separation procedure (α=0.05)

Table 3.3; The effect of fallow management and inorganic-N treatments on above-ground biomass in wheat at 75% heading at Njoro and Rongai during 1998 cropping season.

	Njoro				Rongai			
	← DM yields at *(Mg ha^{-1})*				75% heading →			
	Nitrogen levels (Kg ha^{-1})				Nitrogen levels (Kg ha^{-1})			
Fallow Management treatments	**0**	**30**	**60**	*F-Mgt Means*	**0**	**30**	**60**	*F-Mgt means*
Chickpea	6.72	4.99	6.16	**5.96^{b}**	1.79	2.73	2.02	**2.18^{c}**
Field bean	6.02	9.07	12.09	**9.06^{a}**	2.42	5.82	3.80	**4.01^{ab}**
Soybean	5.14	4.85	7.82	**5.94^{b}**	3.85	3.74	2.68	**3.42^{abc}**
Garden pea	6.44	6.68	6.86	**6.66^{ab}**	3.18	2.97	3.70	**3.28^{bc}**
Dolichos lablab	9.33	9.53	8.57	**9.14^{a}**	2.48	4.90	6.73	**4.70^{a}**
Wheat	6.45	4.65	4.72	**5.27^{b}**	2.34	2.62	3.85	**2.93^{bc}**
Fallow	4.08	5.31	4.32	**4.57^{b}**	2.92	3.46	3.00	**3.13^{bc}**
N Means (Mg ha^{-1})	**6.31^{a}**	**6.44^{a}**	**7.22^{a}**		**2.71^{b}**	**3.75^{a}**	**3.68^{a}**	

Fallow management means followed by the same letter in the column are not significantly different as per Duncan means separation procedure ($\propto=0.05$)
Nitrogen treatment means followed by the same letter in the row are not significantly different according to the Duncan means separation procedure ($\propto=0.05$)

Table 3.4; Effect of fallow management and inorganic-N application on days to 50% heading in wheat at Njoro and Rongai sites

	Njoro				**Rongai**			
			Days to	**50%**	**heading in wheat**			
	Nitrogen levels (Kg ha^{-1})				**Nitrogen levels (Kg ha^{-1})**			
Fallow Management treatments	**0**	**30**	**60**	*F- Mgt Means*	**0**	**30**	**60**	*F-Mgt means*
Chickpea	78.66	83.00	82.00	**81.22**^{a}	73.00	75.00	73.00	**73.66**^{a}
Field bean	82.00	78.66	78.66	**79.77**^{a}	75.66	75.00	71.00	**73.88**^{a}
Soybean	83.00	82.33	82.00	**82.44**^{a}	72.00	73.66	76.00	**73.88**^{a}
Garden pea	80.00	82.00	78.66	**80.33**^{a}	75.00	74.00	73.00	**74.00**^{a}
Dolichos lablab	79.66	83.00	83.00	**81.88**^{a}	73.00	72.66	73.00	**72.88**^{a}
Wheat	80.33	82.00	78.66	**80.33**^{a}	74.66	74.66	71.00	**74.44**^{a}
Fallow	77.33	75.00	77.33	**76.55**^{b}	62.33	62.66	62.33	**62.44**^{b}
N Means (Days)	**80.19**^{a}	**80.85**^{a}	**80.04**^{a}		**72.23**^{a}	**72.52**^{a}	**71.33**^{a}	

CV (%) =3.22 and 4.36 for heading at Njoro and Rongai respectively

Fallow management means followed by the same letter in the column are not significantly different as per Duncan means separation procedure (∝=0.05)
Nitrogen treatment means followed by the same letter in the row are not significantly different according to the Duncan means separation procedure (∝=0.05)

3.3.3 Wheat yield and yield components as influenced by short-rains legume managed fallow

(i) Yield components

The yield and yield components show less clear trends on the effect of fallow management treatments on the performance of wheat. Wheat after dolichos had more tillers at both locations than wheat after the weedy fallow. Tillering in wheat following chickpea, soybean and wheat was similar to that of dolichos at Njoro. Tiller count for wheat at Njoro was almost twice that of Rongai. N application increased tillers at Rongai but no response in wheat at Njoro (Table 3.5). Effect of fallow management treatments on spikelets per spike was significant at Njoro with wheat succeeding dolichos bean giving 19 spikelets which was higher compared to wheat following either fallow or wheat with 17 spikelets. The effect of the other legumes was not large. The response of spikelet numbers to inorganic-N was not registered at both sites. Comparing the two sites, Njoro had 8-14% higher spikelet numbers than Rongai. Seed weight showed similar response to fallow management treatments

Table 3.5; Effect of fallow management treatments on yield and yield components in wheat at Njoro and Rongai in 1998 cropping season

	Njoro			**Rongai**		
	Yield components in wheat (summarized over N)					
Fallow Management treatments	**Tillers /plant**	**Spikelets /spike**	**100-seed weight**	**Tillers /plant**	**Spikelets /spike**	**100-seed weight**
Chickpea	**4.70^{a}**	**18.58^{abc}**	**5.06^{a}**	**2.62^{bc}**	**16.31^{a}**	**4.15^{a}**
Field bean	**3.61^{b}**	**18.66^{ab}**	**4.96^{a}**	**2.42^{c}**	**16.07^{a}**	**4.13^{a}**
Soybean	**4.07^{ab}**	**18.64^{ab}**	**4.78^{a}**	**2.96^{b}**	**16.45^{a}**	**4.09^{a}**
Garden pea	**3.70^{b}**	**18.71^{ab}**	**4.65^{a}**	**2.92^{b}**	**17.13^{a}**	**4.27^{a}**
Dolichos lablab	**4.85^{a}**	**19.33^{a}**	**4.63^{a}**	**3.68^{a}**	**16.97^{a}**	**4.24^{a}**
Wheat	**4.37^{ab}**	**17.89^{bc}**	**4.82^{a}**	**2.38^{c}**	**15.94^{a}**	**4.17^{a}**
Fallow	**3.77^{b}**	**17.30^{c}**	**4.63^{a}**	**1.64^{d}**	**15.89^{a}**	**4.25^{a}**
CV (%)	**18.53**	**6.03**	**8.48**	**18.55**	**10.12**	**6.58**

Means followed by the same letter in the column are not significantly different as per Duncan means separation procedure (∝=0.05)

(ii) Grain yield

There were year differences in wheat grain yields with better yields recorded in 1998 compared to 1999 at the two sites (Table 3.6 a and b). In 1998, wheat grown after field bean gave 28% higher grain yield against wheat succeeding weedy fallow at Njoro while at Rongai, 36% more grain was obtained from wheat following dolichos. The grain yields of wheat succeeding crop-managed fallow were similar but with larger yields associated with legume-managed fallows and the yield harvest was generally larger at Njoro than at Rongai (Table 3.6 a). The N impoverished soils of Rongai showed some benefit accruing from fallow improvement practices that averaged 1.83 Mg ha^{-1} as compared to 1.51 Mg ha^{-1} carried in the unimproved fallow. The wheat-wheat practice gave intermediate grain yields (1.69 Mg ha^{-1}) at this location. N application gave distinct advantages in grain yield resulting in 40 % increase in yields at Rongai, however there was little response to N applied at Njoro. During 1999, wheat grain yield differences were masked and with no clear trends at Njoro whereas it was unresponsive to the fallow management treatments and applied N at Rongai (Table 3.6 b).

Table 3.6; The effect of fallow management treatments on grain yield of succeeding wheat (Mg ha^{-1}) at Njoro and Rongai in (a) 1998 and (b) 1999 cropping seasons.

a) Wheat grain yield in 1998 cropping season

	Njoro				**Rongai**			
	Wheat grain yield (Mg ha^{-1})							
	Nitrogen levels (Kg ha^{-1})				**Nitrogen levels (Kg ha^{-1})**			
Fallow Management treatments	**0**	**30**	**60**	*F- Mgt Means*	**0**	**30**	**60**	*F-Mgt means*
Chickpea	2.75	2.41	2.98	**2.71**^{ab}	1.22	1.53	2.10	**1.62**^{ab}
Field bean	2.68	2.66	2.94	**2.77**^{a}	1.72	1.95	2.10	**1.92**^{ab}
Soybean	2.86	1.96	2.32	**2.32**^{ab}	1.18	1.70	2.57	**1.82**^{ab}
Garden pea	2.34	2.33	2.41	**2.36**^{ab}	1.33	1.63	2.14	**1.71**^{ab}
Dolichos lablab	2.61	2.16	2.59	**2.43**^{ab}	1.57	2.15	2.46	**2.06**^{a}
Wheat	2.16	2.44	2.35	**2.34**^{ab}	1.38	2.00	1.68	**1.69**^{ab}
Fallow	2.21	2.28	2.03	**2.16**^{b}	1.01	1.44	2.11	**1.51**^{b}
N Means (Mgha^{-1})	**2.52**^{a}	**2.32**^{a}	**2.52**^{a}		**1.36**^{c}	**1.78**^{b}	**2.52**^{a}	

CV (%) = 19.98 and 23.13 for grain yield at Njoro and Rongai respectively.

Fallow management means followed by the same letter in the column are not significantly different as per Duncan means separation procedure (α=0.05)
Nitrogen treatment means followed by the same letter in the row are not significantly different according to the Duncan means separation procedure (α=0.05)

b) Wheat grain yield in 1999 cropping season

	Njoro				**Rongai**			
	Wheat grain yield (Mg ha^{-1})							
	Nitrogen levels (Kg ha^{-1})				**Nitrogen levels (Kg ha^{-1})**			
Fallow Management treatments	**0**	**30**	**60**	*F- Mgt Means*	**0**	**30**	**60**	*F-Mgt means*
Chickpea	0.69	0.63	0.49	**0.60**^{bc}	0.78	1.13	1.92	**1.27**^{a}
Field bean	0.89	1.03	1.14	**1.02**^{a}	0.92	1.41	1.46	**1.28**^{a}
Soybean	0.79	0.80	0.79	**0.79**^{ab}	0.76	0.76	1.04	**0.85**^{a}
Garden pea	0.96	0.77	1.17	**0.97**^{a}	1.22	1.18	1.38	**1.28**^{a}
Dolichos lablab	1.12	0.93	0.99	**1.01**^{a}	1.16	1.17	1.28	**1.20**^{a}
Wheat	0.33	0.51	0.45	**0.43**^{c}	1.37	0.88	0.75	**1.00**^{a}
Fallow	0.72	0.80	0.86	**0.79**^{ab}	0.69	0.94	1.49	**0.95**^{a}
N Means (Mgha^{-1})	**0.78**^{a}	**0.78**^{a}	**0.84**^{a}		**1.00**^{a}	**1.09**^{a}	**1.32**^{a}	

CV (%) = 37.46 and 32.77 for grain yield at Njoro and Rongai respectively.

Fallow management means followed by the same letter in the column are not significantly different as per Duncan means separation procedure (α=0.05)
Nitrogen treatment means followed by the same letter in the row are not significantly different according to the Duncan means separation procedure (α=0.05)

3.3.4 Weed biomass and species distribution

Except for Rongai, weed biomass in wheat during 1999 cropping season was higher in plots succeeding short-rains season weedy fallow (Table 3.7). Legume-managed plots reduced weed biomass at Njoro. Dolichos-managed fallow gave the lowest weed biomass although this effect was statistically similar to other legume crops.

Wide range of weed species was noted in plots succeeding natural fallow with perennial weeds dominant over annual weed types. More weed species were found in wheat succeeding the traditional fallow treatment and less in wheat after legume-managed fallow (Table 3.7). Weeds in wheat succeeding legumes and in wheat following wheat were predominantly annuals while wheat following traditional fallow had both annual and perennial weed types (Table A5.3 and A5.4).

Table 3.7; Above-ground weed biomass (Mg ha^{-1}) and species per treatment at 6th leaf stage in wheat at Njoro and Rongai in 1999.

	Weed biomass and species count in wheat crop			
	Njoro		**Rongai**	
Fallow management treatments	**Weed biomass** (Mg ha^{-1})	**Weed species** (No./treat)	**Weed biomass** (Mg ha^{-1})	**Weed species** (No./treat)
Chickpea	$0.04^{b\phi}$	2.25^{a}	0.00^{a}	0.00^{b}
Field bean	0.10^{b}	2.60^{a}	0.06^{a}	0.40^{b}
Soybean	0.07^{b}	2.60^{a}	0.02^{a}	0.16^{b}
Garden pea	0.06^{b}	2.60^{a}	0.02^{a}	0.40^{b}
Dolichos lablab	0.03^{b}	1.75^{a}	0.00^{a}	0.00^{b}
Wheat	0.10^{b}	3.00^{a}	0.00^{a}	0.00^{b}
Fallow	0.43^{a}	3.57^{a}	0.07^{a}	3.16^{a}

Means followed by the same letter in the column are not significantly different as per Duncan means separation procedure (∝=0.05)

3.4 Discussion

3.4.1 Influence of fallow-management practices and applied N on soil-N status, biomass and phenology of succeeding wheat

Growing legumes during short-rains season improved soil nitrogen status, grain yield and quality of succeeding wheat crop. This study observed increased soil available-N in plots previously under legumes compared to plots preceded by either a fallow or cereal (Table 3.3) and the results agree with studies elsewhere (Schultz, 1995; Tanner *et al.*, 1994; Tanner *et al.*, 1991; Reddy *et al.*, 1986). The contribution of fallow management treatments to soil N seems not to depend entirely on biomass production of the fallow species (Table 2.1). The quantity of residue incorporated did not correspond to soil N suggesting influence of other factors related to quality of the residue. Tissue polyphenol, lignin and N content are among factors that have been suggested to influence ease and rate of mineralization of organic residue and subsequent nutrient release to the soil (Tian *et al.*, 1994; Handayanto *et al.*, 1992; Fox *et al.*, 1990). Given the nature and scope of this study, it was not possible to determine mineralization rate for each of the fallow management treatments. However, investigations by Palm (1995) indicated that initial N release from organic sources is dependent on tissue per cent N as primary factor and per cent polyphenol as secondary. In this study, dolichos emerged as a leading contributor to soil nitrogen yet it had relatively low biomass but with exceptionally high tissue N content (Table 2.1 and 2.4). Also there is an apparent gain in wheat biomass when wheat is grown subsequently to legumes, as compared to fallow-wheat or monoculture sequences (Table 3.3). This can be explained on the basis of the improved soil N associated with legumes (Table 3.1) which impacts positively on tillering and crop canopy development (Table 3.5). The response of wheat biomass build up to inorganic N supply was only marginal at Njoro but large at Rongai (Table 3.3). This difference may be attributed to lower soil residual N at Rongai compared to Njoro (Table A1.1).

Nutrient uptake by plants is greatly influenced by its availability in the soil nutrient pool. Though there is an optimum level for each element, high N content in the grain and vegetative tissue is an indication of adequate supply of N in soil nutrient pool. Badaruddin and Meyer (1994) observed a greater N accumulation by wheat following grain legumes against wheat following fallow. The improved soil N associated with legumes could also be a factor in the observed elevated wheat dry matter accumulation rate in which dolichos stimulated larger increases in growth and development (Table A3.1). Results of this study indicate that dolichos is capable of providing soil available N sufficient to meet the demands of succeeding wheat and this effect was consistent regardless of location (Table A3.5). The impact of other legume fallow improvement practices were less noticeable. The comparative advantage of dolichos probably emanates from its deep root system and its ability to nodulate readily inspite of dry field conditions.

The observed differences in biomass yield between locations is mainly due to temperature. Njoro is a cool environment compared to a relatively warm, dry Rongai environment (Figs. A3.1 and A3.2). Under low temperature, crops take longer time to shift from one stage to the next and undergo a longer duration of growth if other factors remain favourable (Squire, 1990). Delayed crop growth as induced by mild growing temperatures allows the crop to accumulate more DM therefore higher biomass production (Table 3.3). Besides influencing growth rate, temperature has a bearing on the energy balance of the plants. Under relatively high temperatures considerable amount of energy in plants is spent in cooling their system and this negates net assimilation rate (Forbes and Watson, 1992).

The difference in phenological change from vegetative to reproductive was quite distinct among fallow management treatments with wheat succeeding the traditional fallow heading much earlier than crop-managed fallow. Crops under stress especially moisture stress tend to hasten vegetative phase in favour of reproductive phase as a survival strategy (Donaldson, 1996). However, soil moisture stress could not be a factor in this study since wheat under all treatments was exposed to similar rain-fed conditions. In addition, large quantities of organic residues were incorporated in plots succeeding the weedy fallow therefore a comparatively greater soil moisture could be retained. The possible factor responsible for early phenological change in wheat succeeding traditional fallow could be nitrogen stress or allelochemicals as constituents of weedy species. Though soil N in the previous weedy fallow as taken four weeks after sowing of wheat was less distinct from the other treatments (Table 3.1), vegetative tissue-N at physiological maturity in wheat grown in previous fallow plots was noticeably low (Table A3.5). This suggests insufficient soil available N. A further indication of N stress as a factor in heading of wheat is site differences. Wheat succeeding the weedy fallow headed 4-5 days and 10-13 days earlier than wheat following crop-managed short-rains season at Njoro and Rongai respectively. Soil N analysis indicates site differences with the Njoro showing higher available N levels than Rongai (Table 3.1). This implies that the shortening of days to heading in wheat as influenced by soil N stress would be more pronounced at Rongai and less at Njoro. These results are corroborated by a study in Egypt by Kheiralla and Ismail (1995), involving several cultivars and three levels of N which found that increasing N rate resulted in increased days to heading.

3.4.2 Yield and yield components

The reduced grain yield in 1999 compared to 1998 cropping season was caused by unusually dry spell at early wheat growth stages in the former year (Fig. A3.1 and A3.2). Wheat response to the fallow management treatments was therefore hampered in 1999 cropping season since soil moisture is crucial for mineralization of organic residue and adequate uptake of soil mineral nutrients. The total precipitation in 1999 was only 264 and 366 mm compared to 520 and 560 mm in 1998 for Njoro and Rongai respectively during the April-August long-rains cropping season.

Soil fertility is a crucial factor influencing yield and protein content in wheat given favourable soil moisture and weather conditions (Metho *et al.*, 1997). Spikelet numbers and spikes per unit area are important yield components directly influenced by soil nutrient status. The number of tillers and spikelets per spike increased with improved soil-N status which generally led to better yield in wheat succeeding legumes particularly dolichos (Table 3.5). Soil-N has been reported as one of the key factors responsible for increased tillers (Khalil *et al.*, 1994). Schultz, (1995) found out that wheat seed weight remained constant over seasons in a cereal and legume rotation trial and that yield variations were largely due to differences in tiller numbers or spikelets per spike and therefore seed number. In another study, Roy and Biswas (1991) observed significant correlation between grain yield and number of ears (spikelets) per square metre. Results in the present study are consistent with these findings and strongly suggest that tiller and ear numbers contribute immensely to the final grain yield. Hence larger yields associated with fallow management species notably dolichos, are mediated by enhanced soil N which induces more profuse production of tillers and spikelets resulting in increase in grain yield.

3.4.3 Weed biomass and weed species distribution

Frequent cultivation of arable land curtail completion of life-cycle of most weeds consequently weakening their invasion in succeeding crops. Weed occurrence under continuous cropping such as relay or sequential cropping is greatly reduced and mainly limited to the annual type whose short life-cycle can allow continued survival despite frequent cultivation. Cropping system with short fallow break allows most weeds to complete their growth cycles thereby increasing the weed seed bank which subsequently leads to serious weed infestation in future crops. The results presented above indicate increased weed biomass and species observed in wheat succeeding a fallow in contrast to continuous cropping practices, notably where legumes were involved probably due to variations in ground cover and light attenuation.

Land left fallow allowed build up of weeds through multiplication of vegetative organs and return of mature seed to soil reservoir thus strengthening their regenerative capacity. The increased weedy species density and distribution in wheat succeeding the traditional fallow (Table 5.3 and 5.4) reflect a regenerative reservoir build up during the fallow break which ultimately gave higher weed biomass during the test crop phase.

The weedy fallow was associated not only with larger population of annuals, but perennial weeds such as: *Conyza sp.*, *Pennisetum clandestinum* and *Digitaria scalarum* (Table A5.3). In his assessment of weed population dynamics, Sibuga *et al.* (1997) reported a buildup of perennial weeds under fallow against continuous cultivation or rotation system which corroborate findings in this study. The reduction in weed species distribution under continuous cropping is attributed to the management of perennial type which cannot withstand frequent cultivation due to their extended life-cycles. In contrast, annual weeds had better chance of recurrence due to short growth cycle and hence the high frequency across fallow management treatments compared to the perennial type. Annual weeds which were frequent include *Amaranthus hybridus*, *Galinsoga parviflora* (for both Njoro and Rongai), *Setaria pulludfusca* and *Brassica napus* (Njoro). *Cyperus sp.* was notably common across fallow management systems and was able to withstand frequent cultivation due to presence of regenerative bulbs and tubers which can become dormant if conditions are not favourable.

Managed fallow essentially reduce or change weed species composition and density and this shift can be attributed to management practices during the fallow which are unfavourable for weed growth. Legumes in this study acted as cover crops and notably dolichos and garden pea whose sprawling growth habit ensured good ground cover. Thick canopy spread above the ground attenuates light allowing small fraction of the total received above the canopy reaching the ground. Light is a requirement for germination of seed of some weed species and any obstruction either by mulches or cover crop reduces light availability for weed seeds thereby hindering their germination (Wilson, 1988; Egley and Duke, 1985). Unfortunately, due to unavailability of a ceptometer or other relevant solarimeters, the exact canopy radiation environment characterization could not be determined.

In the absence of adequate weed management, crop yields would be substantially depressed by weeds owing to the identical demands for both crops and weedy species on natural resources particularly light and nutrients (Akobundu, 1993). The impact of weeds on crop yields confounded by declining soil fertility therefore has enormous deleterious potential on the test crop. The results of this study clearly indicate that unmanaged fallow break during the short-rains season exacerbates weed problem in succeeding wheat crop, and carries the potential of reducing crop yields.

3.5 Reference

Akobundu, I.O. 1993. Integrated weed management techniques to reduce soil degradation. IITA Research No.6. Ibadan, Nigeria. 11-16.

Altieri, M. A. and M. Liebman. 1986. Insect, weed and plant disease management in multiple cropping systems. In: Charles A. Francis (ed.) Multiple Cropping System. Macmillan Publishers, NY. 183-218.

Badaruddin, M. and Meyer, D.W. 1994. Grain legume effects on soil nitrogen, grain yield and nitrogen nutrition of wheat. Crop Science. 34:1304-1309.

Donaldson, E. 1996. Crop traits for water stress tolerance. American Journal of Alternative Agriculture. USA. 11: 86-94.

Egley, G.H. and Duke, S.O. 1985. Physiology of weed seed dormancy and germination. In: Stephen O. Duke (ed.) Weed Physiology V.II; Reproduction and Ecophysiology. CRC press, Inc.

Forbes, J.C. and R.D. Watson. 1992. Harnessing of energy by plants. *In*: Plants in Agriculture. University Press, Cambridge, USA. pp 12-20.

Fox, R.H., R.J.K. Myers and I. Vallis. 1990. The nitrogen mineralization rate of legume residues in soil as influenced by their polypheneol, lignin, and nitrogen content. Plant and Soil 129: 251-259.

Franzluebbers, A.J., F.M Hons and V.A Saladino. 1995. Sorghum, wheat and soybean production as affected by long term crop sequence and N-fertilization. Plant and Soil. 173:55-65.

GOK. 1998. Economic Survey. Central Bureau of Statistics, Office of the Vice President and Ministry of Planning and National Development, Government Printers, Nairobi-Kenya. p129-132.

Guto, S.N. 1997. Effects of chickpea (*Cicer arietinum* cv. Kaburi) and common beans (*Phaseolus vulgaris* L. cv. Rose coco) on wheat performance and soil fertility in a legume-wheat cropping sequence. MSc thesis, Egerton University, Njoro, Kenya.

Handayanto, E., Y. Nuraini, P. Purnomosidi, M. Hanegraaf, G. Agterberg, J. Hassink and M. van Noordwijk. 1992. Decomposition rates of legume residues and N-mineralization in an ultisol in Lampung. AGRIVITA. 15:75-86.

Hassan, R.M., W. Mwangi and D. Karanja. 1993. Wheat Supply in Kenya: Production Technologies, Sources of Inefficiency and Potential for Productivity Growth. CIMMYT Economics Working Paper No.93-o2. Mexico, D.F.: CIMMYT. pp 1-4.

Jaestzold, R. and H. Schmidt. 1983. Farm management hand book of Kenya. Vol. II/B Central Kenya. Ministry of Agriculture, Kenya in Coorperation with German agricultural team (GAT) of German Agency of Technical Cooperation (GTZ).

KARI. 1992. Improve and sustain maize production through adoption of known technologies. Information Bulletin, Kenya Agricultural Research Institute, Nairobi, Kenya.

KARI. 1997. Crop production guidelines for wheat, oilcrops and horticulture. Arama, P.F., J.K. Wanjama, F. Kiriswa and P.K. Macharia. (eds). National Plant Breeding Research Centre, Njoro.

KARI and MIAC. 1993. Strategic plan for Cereals in Kenya (1993-2013). Kenya Agricultural Research Institute, Nairobi, Kenya.

Khalil, A., M.Q. Khan and S. Zahir. 1994. Effect of fertility level on the performance of wheat varieties in Dera Ismail Khan. Sarhad Journal of Agriculture. 10:121-124.

Kheiralla, K.A. and A.A. Ismail. 1995. Stability analysis for grain and some traits related to drought resistance in spring wheat. Assiut Journal of Agricultural Sciences. 26:1, 253-266.

Kinyua, M.G., J.K. Wanjama, J. Kamwaga and S.N. Mwigi. 1989. Current situation of wheat production in Kenya. Kenya Agricultural Research Institute, Nairobi, Kenya.

Metho, L.A., P.S. Hammes, J.M. de Beer and H.T. Groeneveld. 1997. Interaction between cultivar and soil fertility on grain yield, yield components and grain nitrogen content of wheat. South Afri. Tydskr. Plant Grond. 14: 158-164.

Mloza-Banda, H.R. 1997. Changes in weed species composition in maize-based cropping system in central Malawi. In: The 16th East African biennial weed science conference proceedings, Kampala, 15-18 Sept. 1997. 71-79.

Muriuki, E.M. 1998. Report of the ECAMAW working group meeting on soil fertility issues in maize and wheat based system in Eastern and Central Africa. 15-19th November 1998, Mombasa Kenya.

Mwaja, V. and J. Masiunas. 1997. Sustainable weed management systems in agriculture: A review. In: The 16th East African biennial weed science conference proceedings, Kampala, 15-18 Sept. 1997. 21-32.

Okalebo, J.R., K.W. Gathua and P.L. Woomer. 1993. Laboratory Methods of Soil and Plant Analysis: A working manual. Tropical Soil Biology and Fertility Programme. Nairobi, Kenya.

Onwonga, R.N. 1997. Effect of chickpea incorporation on soil nutrient status and wheat grain yield in a wheat-chickpea rotation. MSc thesis, Egerton University, Njoro, Kenya.

Page, A.L., R.H. Miller and D.R. Keeney. 1982. Methods of Soil analysis Part 2; Chemical and microbiological properties. American Society of Agronomy, Madison, USA.

Palm C.A. 1995. Contribution of agroforestry trees to nutrient requirements of intercropped plants. Tropical Soil Biology and Fertility Programme, Nairobi, Kenya. Agroforestry System, Kluwer Academic Publishers, Netherlands. 30:105-124.

Reddy, K.C., A.R. Soffes and G.M. Prine. 1986. Tropical Legumes for Green Manure. In: Nitrogen Production and the Effects on Succeeding Crop Yields. Agronomy Journal. 78:1-4.

Roy, S.K. and P.K. Biswas. 1991. Effect of population on tillering growth, yield components and yield of wheat. Annals of Bangladesh Agriculture, Bangladesh. 1: 81-85.

SAS institute. 1996. SAS for windows 6.12. Cary NC USA.

Schultz, J.E. 1995. Crop production in a rotation trial at Tarlee, South Australia. Australian Journal of Experimental Agriculture. 35:7, 865-876.

Sibuga, K.P., E.E. Mugogo and Z. Masele. 1997. Preliminary assessment of weed population dynamics and distribution in soil under different management systems. In: The 16th East African biennial weed science conference proceedings, Kampala, 15-18 Sept. 1997. 89-95.

Squire, G.R. 1990. Dry matter production and solar radiation. In: The Physiology of Tropical Crop Production. CAB International, Wallingford, UK. 73-99.

Steel, R.G.D., J.H. Torrie and D. A. Dickey. 1997. Principles and practices of statistics, a biometrical approach. McGraw-Hill Companies, Inc.

Taa, A., D.G. Tanner, K. Girma and A. Gorfu. 1997. Grain yield of wheat as affected by cropping sequence and fertilizer application in South Eastern Ethiopia. African Crop Science Journal. 5: 147-159.

Tanner, D.G., A. Gorfu and K. Zewde. 1991. Wheat agronomy research in Ethiopia. In: Wheat Research in Ethiopia: A Historical Perspective. Hailu Gebre-Mariam, Tanner, D.G and Mengistu Hulluka (eds.) IAR/CIMMYT, Addis Ababa, Ethiopia. pp 95-136.

Tanner, D.G., Z. Yilma, L. Zewdie and G. Gebru. 1994. Potential for cereal-based double cropping in Bale region of Southeastern Ethiopia. African Crop Science Journal. 2:135-143.

Tian, G., B.T. Kang and L. Brussaard. 1994. Mulching effect of plant residues with chemically contrasting compositions on maize growth and nutrients accumulation. International Institute of Tropical Agriculture (IITA) Research No 9: 7-11.

Wilson, R.G. 1988. Biology of weed seeds in the soil. In: Altieri M. A. and Matt Liebman. Weed Management in Agroecosytems: Ecological Approaches. CRC Press.

Wortmann, C.S., M. Isabirye and S. Musa. 1994. *Crotalaria ochroleuca* as a green manure crop in Uganda. African Crop Science Journal. 2:55-61.

Chapter Four

The Effect of Selected Grain Legumes on Nitrogen Dynamics and the Performance of Maize (*Zea mays* L.) in a Legume-Maize Cropping Sequence in Kenya Highlands.

Abstract

Maize (*Zea mays* L.) is a primary food crop in Kenya and is cultivated country wide. Its production is slightly less than consumption and is produced mainly in agriculturally high potential zones of the Kenya Highlands. Production is mainly limited to the long rains season occurring in April-August. After harvest, majority of farmers fallow their land during the October-December short rains season as they wait for next cropping. The average maize yield is 1.5 tons ha^{-1} against a potential of 7 tons ha^{-1}. High input costs especially fertilizers coupled with declining soil fertility have contributed to the low yields. In an effort to improve maize yield through sustained soil fertility, a field experiment was set to study the contribution of five legumes grown in the short-rains season to soil nitrogen status and performance of succeeding maize crop. The experiment was set up at Egerton University, Njoro and Rongai both within the Kenya Highlands and included a fallow, five legumes and maize (H513) grown during short-rains season and each followed by maize in the April-August long-rains

season. The legumes were chickpea *(Cicer arietinum* L.), field bean (*Phaseolus vulgaris* L.), soybean [*Glycine max*(L.) Merril], garden pea.(*Pisum sativum* L.), dolichos lab lab [*Lablab purpureus* (L) Sweet]. Their crop residues including the cereal and vegetation in the fallow were incorporated in the soil during seedbed preparation. The influence of the short-rains management system on soil nitrogen status and response of succeeding maize was determined by soil sampling for N analysis, crop biomass, leaf area index, ear count, grain yield, vegetative tissue-N and grain-N. Results show improved soil N status following legumes, with dolichos giving highest available N. Grain yield in maize succeeding legumes was 24-68% higher than maize succeeding weed fallow and in absence of N fertilizer input, maize succeeding dolichos gave 20-40% higher yield than maize after weed fallow treated with recommended 60 kg N ha^{-1} fertilizer rate. Reduction in weed incidence was observed in maize following legume-managed fallow. Use of legumes, particularly dolichos in rotation with maize has large benefits as reflected in improved grain yields and reduction of fertilizer inputs.

4.1 Introduction

Maize (*Zea mays* L.) is a primary food crop in Kenya (GOK, 1994) and is cultivated country wide. Annual production estimated at 2.7 million tonnes is reported as being slightly less than consumption (KARI & MIAC, 1993). Besides frequent unfavourable weather conditions, cost of production especially input costs have greatly constrained maize production (Muriuki, 1998). Kenya's population is projected at 36 million in the year 2010, up from current 27 million. Per capita arable land has declined over the years from 0.23 to 0.15 hectares in 1981 and 1996 respectively (World Bank, 1998) suggesting the need to step up yields per unit area (KARI, 1992).

Crop nutrition is an essential component influencing maize yields. Since inorganic fertilizers have become less affordable to farmers, their insufficient use has greatly depressed maize grain yield. Alternative sources to soil nutrient replenishment that are less expensive, readily available to farmers and which can increase or sustain maize grain yield are needed. Legumes are expected to enrich soil through biological nitrogen fixation and mineralization of organic residues. Cereals succeeding legumes have shown increased grain yields which is mainly attributed to improved N following mineralization of the legume residues (Oike *et al.*, 1998; Kwesiga & Coe, 1994; Wortmann *et al.*, 1994; Onim *et al.*, 1990). Besides, legume-cereal cropping sequence have been shown to reduce weed incidence in cropland (Altieri and Liebman, 1986; Mloza-Banda, 1997; Mwaja and Masiunas, 1997).

The Kenya Highlands have a bimodal rainfall pattern occurring in April-August and October-December referred to as long-rains and short-rains respectively. Rainfall received in the long-rains season is about 300-600 mm against 250-400 mm in the October-December short-rains season (Jaetzold and Schmidt, 1983). Farmers intensify their cropping during the long-rains season and majority fallow their land in the short-rains season. The short-rains season is characterized by low and erratic rainfall forcing most farmers to fallow their land. The relatively dry short-rains season can be utilized in production of suitably adapted legumes whose residues can be incorporated into the soil to benefit a succeeding maize crop. A study done in Ethiopia revealed that traditional short fallows can be profitably managed with crops and that improved grain yields of succeeding cereals can be realized if that crop is a legume (Tanner *et al.*, 1994). Adaptability of some promising legumes to the semi-dry fallow gap indicate that legumes can be integrated in cereal production with positive yield results (Mwandemele, unpublished data; Rheenen *et al.* 1991; Guto, 1997; Onwonga, 1997). However there is little reliable information on fallow improvement with grain legumes under the Kenya Highlands conditions. This study focused on management of the October-December fallow gap with five legumes against a continuous cereal and the traditional fallow. Legumes in the study were; chickpea *(Cicer arietinum* L.), field bean (*Phaseolus vulgaris* L.), soybean [*Glycine max*(L.) Merril], garden pea (*Pisum sativum* L.), dolichos lab lab [*Lablab purpureus* (L) Sweet]. Residues that accrued from the seven management approaches were hand hoed prior to sowing of maize in the following cropping season and their influence on soil N status and performance of succeeding maize crop observed. The study tested three hypotheses; that growing of legumes during the short-rains season in the Kenya Highlands increases grain yield of succeeding maize and that the yield increase is associated with improved soil N attributed to the legumes and secondly, that different legume genotypes grown in the short-rains season vary in their contribution to soil N and that this variation induced differences in the performance of succeeding maize in the legume-maize cropping sequence and thirdly, that managing the fallow checks the growth of weeds thereby reducing their interference potential in the succeeding maize crop.

4.2 Materials and Methods

4.2.1 Site description

Two similar experiments were set up in Nakuru District within Rift Valley Province. One was set up at Egerton University farm located in Njoro Division and the other at a farmer's field at Mangu, in Rongai Division both of which are in agriculturally high potential zone III-(6) and III-(5) of the Kenya Highlands

(Jaetzold and Schmidt, 1983). The two sites are about 30 km apart and have distinct soil differences.

Mangu is at an altitude of 1945 m above sea level and receives annual rainfall of about 900 mm with a mean annual temperature range of 16-18°C. The soils are well drained sandy clay loam (Vitric Andosols). Egerton University is at an altitude of 2250 m above sea level and receives annual precipitation of about 1000 mm and has a mean annual temperature range of 14-16°C. The soils are well drained Mollic Andosols.

4.2.2 Experimental design and treatments

Each experiment had 21 treatments under Randomized Complete Block Design (RCBD) arranged in split plots and replicated three times following procedures suggested by Steel *et al.*(1997). Three levels of N-fertilizer (0, 30, and 60 kg) N ha^{-1} were assigned to whole plots measuring 4x21 m with fertilizer source being Calcium Ammonium Nitrate ($NH_4NO_3+CaCO_3$). Sub-plots measured 4x3 m and carried seven treatments consisting of five grain legumes, maize (H513) and a natural fallow. Of this treatment factor level, apart from maize and weedy fallow, the legumes included; chickpea *(Cicer arietinum* L.), field bean (*Phaseolus vulgaris* L.), soybean [*Glycine max*(L.) Merril], garden pea (*Pisum sativum* L.), dolichos lab lab [*Lablab purpureus* (L) Sweet]. These treatments were applied during the short-rains season starting in October-December and were evaluated for their suitability as alternatives to managing fallows during this period and therefore termed as fallow management treatments (F-mgt). The whole-plot treatments were applied to test-crop maize at V6 growth stage (Ritchie *et al.*, 1986) during the April-August long-rains season.

The fallow management precursor crops were grown during the October-December short rains seasons in 1997 and 1998. The seedbed was tilled with hand hoe for all the six treatments except for the fallow treatment which was left untilled. Sowing of the crops was done on 23rd and 25th October in 1997, 29th and 31st October in 1998 for Egerton and Rongai sites respectively. Each of the crops were seeded in October at recommended spacing; chickpea 30x10 cm, field bean 50x20 cm, soybean 45x15 cm, garden pea 45x15 cm, dolichos lablab 60x30 cm and maize (H513) 75x30 cm. Inorganc-P with Triple Super phosphate [$Ca(H_2PO_4)_2H_2O$] as source was applied at 60 kg P_2O_5 ha^{-1} which is the generally recommended rate for both cereals and legumes in the region (KARI, 1997). Other non-experimental cultural practices were carried out as recommended by the same authorities. Harvesting of the crops which seeded was done between January and February the following year depending on when each crop matured. During harvesting, the grains were taken while the rest of vegetative material was left in the field for subsequent incorporation into the soil during land preparation. Seedbed preparation was carried out in March for all treatments and it involved incorporation of crop/vegetative material into the soil for each experimental unit in preparation for maize sowing during the April-August long rains season in 1998 and 1999. Seedbed was prepared by use of hand hoes.

The effect of the fallow management treatments on soil nutrient status and particularly N was observed on the succeeding maize crop during the local cropping season starting in April. Hybrid Maize seed 'H513' was sown in each of the previous fallow management treatment plots at onset of rains. The seed was sown at 75x30 cm with two seeds per hill and later thinned to one seedling per hill. Inorganic-P was applied at 60 kg P_2O_5 with TSP as source. Sowing was done four weeks after the incorporation of crop/vegetative residue. Literature indicates that optimum mineralization for most residue occur between 6-8 weeks after incorporation (Handayonto *et al.*, 1992) and sowing four weeks after residue incorporation was to synchronize the linear growth phase in maize with time when mineralized soil-N is expected to be at optimum level. The N-fertilizer treatments were applied at V6 growth stage. Other crop management practices were done as recommended except those due to treatments. Maize was harvested in October 1998 and the second cycle of the experiment was repeated in 1999 with the treatments maintained in the same plots

4.2.3 Parameters and sampling procedures

(i) Parameters

The suitability of the fallow species to fallow improvement was predicted on their adaptive characteristics to the semi-dry, short-rains season which include; biomass production, stand count, nodulation capacity, tissue-N and grain yield (Chapter 2). Estimates of biomass production by the fallow management treatments together with vegetative tissue-N was determined to quantify their contribution to both organic matter and soil N. The influence of fallow management treatments on soil nutrient status especially N alongside interaction of inorganic-N was observed through the succeeding maize response indices. The following are the parameters and sampling procedures used to achieve the above.

(ii) Sampling the fallow management species

The growth, biomass yield, vegetative tissue N and C/N ratios of the fallow management species was discussed earlier (Chapter 2).

(iii) Sampling during test crop (maize)

Soil samples were taken six weeks after fallow residue incorporation as earlier studies indicate that this time corresponds to peak residue mineralization (Handayonto *et al.*, 1992). Two soil samples each at 0-15 cm and 15-30 cm depth in each plot were put in a small labelled polythene bag, stapled and kept in a fridge as they awaited N-analysis.

Weed data was taken at V4 growth stage in maize, prior to first weeding of the crop. In this study, a metre square (m^2) quadrat was thrown in the middle of each plot. All weed species within the quadrat were identified, counted and recorded. Above-ground biomass of the weeds within the quadrat was harvested for dry matter analysis. The weeds were dried at 65°C to constant weight and dry weight determined. The total weed count in each plot was used to calculate for species density and relative per cent. After sampling, maize was weeded manually using hand hoes and this operation was repeated two more times before physiological maturity in maize (KARI, 1997). Because of this conformity effect, the impact of weeds on maize crop yields was not directly assessed. The data presented focused on responses in 1999 to allow for cumulative effect of fallow management practices in the previous two short-rains seasons.

Maize sampling for DM determination was done at V6 , R2 and at physiological maturity growth stages as described by Ritchie *et al* (1986). Three plants were sampled at the crown level in each plot. The 4th and 6th plants in the second row and a 5th in third row were consistently picked in sequence. They were dried at 65°C for a minimum of 48hrs to constant weight. In addition, whole plants sampled at physiological maturity were separated into grains and vegetative tissue and each was milled for tissue-N analysis.

During vegetative crop development, three plants in each plot were marked and used to monitor leaf area development through determination of leaf area index (LAI). Each leaf of marked maize plant was measured in two directions; length from ligule to apex (ℓ) and the broadest width of leaf blade (w). The product of the two for each leaf was multiplied by a coefficient k determined to be 0.75 thus giving an estimated leaf area following standard procedures (Norman and Campbell, 1989). The total leaf area for each plant was divided by plant effective soil area which is equivalent to the plant's spacing (75x30 cm) to give leaf area index (LAI). The average LAI was obtained from the three plants in each plot to get a representative figure and this is an estimate of crop canopy development in relation to soil area. During harvesting, six centre plants from two middle rows were harvested, shelled and dried for grain yield determination. The total cobs from the six plants were counted and divided by six to give average cobs per plant.

4.2.4 Chemical analysis

(i)Total N in plant tissue

0.3 g of oven-dried (65°C) ground plant tissue (2 mm) was taken in a dry clean digestion tube. 10 mls of conc. H_2SO_4 and one tablet containing lithium sulphate and selenium were added and content digested at 360°C for 2 hours. The digest was left to cool then dissolved in distilled water and made upto 50 ml before being allowed to settle. Total N was then determined by distillation and titration as given by Page *et al.* (1982) and mordified by Okalebo *et al.*,(1993).

(ii) Soil available N

8 g of fresh soil was taken in 100ml plastic bottles, extracted with 80 mls of 2M KCl and contents shaken in mechanical shaker for one hour. After settling, 10 mls aliquot of the extracted soil was taken in distillation tube and about 0.2 g MgO and 0.2 g Devarda's alloy was added and content distilled for three minutes using automatic kjedhald distiller. Both NO_3^- -N and NH_4^+-N were collected with 5mls fresh boric acid indicator and titrated with 0.002N H_2SO_4 (Page *et al.*, 1982; Okalebo *et al.*, 1993)

(iii) Organic carbon

0.03 g ground plant tissue was weighed into 500 ml conical flask and 10 ml 1M $K_2Cr_2O_7$ solution and 20 ml conc. H_2SO_4 was added and swirled gently then left for 30 minutes. After elapse of 30 minutes, 200 mls of distilled water and 10 mls of othophosphoric acid was added and the solution titrated with 0.2 M ferrous ammonium sulphate. Per cent carbon was determined thus; $\%C=0.003 \times 0.2(V_b-V_t) \times 100/_w$, where V_b is volume of blank titre , V_t volume of sample titre and $_w$ is weight of the sample taken. C/N ratio was calculated by dividing per cent carbon with the corresponding per cent N in (a) above. This procedure has been described by Okalebo *et al.*, 1993.

All data collected from the dependent variables was processed and subjected to analysis of variance and mean separation procedures as outlined elsewhere (SAS Institute, 1996; Steel *et al.*, 1997).

4.3 Results

4.3.1 Influence of fallow management residues on soil-N status during maize cropping season

The influence of organic residues from the fallow management treatments on soil N (NH_4^+-N + NO_3^--N) as determined eight weeks after their incorporation shows variable effects (Table 4.1). However, there were notable effects in plots previously under dolichos where consistently large amounts of N were measured against plots after the weedy fallow. Except for 1998 results at Rongai, the difference in soil available N following crop-managed fallows were negligible. However, plots succeeding dolichos at Rongai in 1998 had higher N compared to the other fallow management treatments.

Above-ground biomass of incorporated residue from the fallow management species and the residue quality as measured by N content and C/N ratio was discussed earlier in chapter 2.

Table 4.1; Effect of fallow management treatments on soil available-N at eight weeks after residue incorporation (four weeks after sowing maize).

	Njoro (1999)		**Rongai (1998)**		**Rongai (1999)**	
	Soil available N (µg N/g soil)		**Soil available N (µg N/g soil)**			
	sampling depth		**sampling depth**			
F-Management treatments	**0-15cm**	**15-30cm**	**0-15cm**	**15-30cm**	**0-15cm**	**15-30cm**
Chickpea	324.5$^{a\Phi}$	268.8^{ab}	88.9^{b}	94.9^{b}	390.1^{ab}	253.1^{ab}
Field bean	347.9^{a}	276.4^{ab}	71.6^{b}	106.1^{b}	375.6^{ab}	332.1^{a}
Soybean	374.8^{a}	333.8^{a}	90.0^{b}	86.3^{b}	305.8^{ab}	265.6^{ab}
Garden pea	326.1^{a}	289.4^{ab}	88.2^{b}	72.7^{b}	376.7^{ab}	322.9^{a}
Dolichos lab lab	381.5^{a}	328.8^{a}	139.1^{a}	155.3^{a}	441.5^{a}	361.4^{a}
Maize	402.1^{a}	304.5^{ab}	69.6^{b}	94.1^{b}	360.2^{ab}	283.2^{ab}
Fallow	331.5^{a}	228.5^{b}	90.9^{b}	100.3^{b}	275.8^{b}	192.7^{b}
CV (%)	**25.3**	**29.6**	**51.4**	**40.1**	**35.9**	**35.2**

$^{\phi}$ Means followed by the same letter in the column are not significantly different as per Duncan means separation procedure ($\propto$=0.05)

Soil available N for 1998 at Njoro was avoided due to cost in analysis

4.3.2 Influence of fallow management treatments on growth and development of maize crop

There was marked locational difference in growth response to treatment as determined by DM accumulation (Table 4.2). Increased growth was recorded in maize preceded by dolichos at both sites but notably at Rongai. Applied N appreciably increased growth at the same location. However, N fertilizer showed no significant influence on DM accumulation in maize at Njoro.

Maize canopy development as indicated by leaf area index (LAI) was improved for maize following dolichos compared to maize preceded by traditional fallow and maize at the two locations (Table 4.3). In comparison with dolichos, the rest of the legumes preceding maize had similar influence on maize leaf area development at Njoro but their impact was less significant at Rongai. There was no registered response in maize LAI to applied N at the two locations at this stage of crop development.

Above-ground maize overall biomass at R2 closely followed that of LAI; maize after dolichos produced larger biomass yield at both sites (Table 4.4). Other than dolichos, the effects of the other legumes on maize biomass were not clearly separable from each other. However, all legumes were associated with slightly higher DM build up as compared to maize-maize or weedy fallow-maize practices. In general, biomass yield at Njoro was almost twice that of Rongai at R2. Inorganic N had larger effect on biomass at Rongai but no clear pattern emerged at Njoro.

Table 4.2; Effect of fallow management and applied N on dry matter (DM) accumulation (gms day^{-1}) in maize between V6 and R2 growth stages during 1998 cropping season.

	Maize DM accumulation (gms day^{-1})							
	Njoro				**Rongai**			
	Nitrogen levels (Kg ha^{-1})				**Nitrogen levels (Kg ha^{-1})**			
Fallow management treatments	**0**	**30**	**60**	***Fallow Mgt means***	**0**	**30**	**60**	***Fallow Mgt means***
Chickpea	5.48	4.72	5.04	**5.08^{a}**	1.93	3.06	4.48	**3.16^{b}**
Field bean	4.16	6.71	4.10	**4.99^{a}**	2.37	2.39	4.74	**3.17^{b}**
Soybean	6.11	6.47	4.36	**5.65^{a}**	1.99	4.24	2.25	**2.83^{b}**
Garden pea	5.43	4.06	7.87	**5.79^{a}**	3.00	2.80	3.93	**3.24^{b}**
Dolichos lablab	8.19	5.68	5.62	**6.50^{a}**	4.65	5.23	5.21	**5.03^{a}**
Maize	3.98	2.70	3.55	**3.41^{a}**	2.12	2.71	2.81	**2.55^{b}**
Fallow	3.74	3.60	4.18	**3.84^{a}**	2.45	2.70	3.38	**2.84^{b}**
N means (gms day^{-1})	**5.30^{a}**	**4.85^{a}**	**4.96^{a}**		**2.64^{b}**	**3.30^{ab}**	**3.83^{a}**	

Fallow management means followed by the same letter in the column are not significantly different as per Duncan means separation procedure ($\propto=0.05$)
Nitrogen treatment means followed by the same letter in the row are not significantly different according to the Duncan means separation procedure ($\propto=0.05$)

Table 4.3; Influence of fallow management and N fertilizer treatments on leaf area index (LAI) at V9 growth stage in maize during 1998 cropping season.

	Leaf area index (LAI) at V9							
	Njoro				**Rongai**			
	Nitrogen levels (Kg ha^{-1})				**Nitrogen levels (Kg ha^{-1})**			
Fallow management treatments	**0**	**30**	**60**	***Fallow Mgt means***	**0**	**30**	**60**	***Fallow Mgt means***
Chickpea	1.64	1.30	1.04	**1.33**^{a}	1.31	0.87	1.54	**1.24**^{b}
Field bean	1.95	1.20	1.29	**1.48**^{a}	0.98	1.19	1.34	**1.17**^{b}
Soybean	1.31	1.80	1.56	**1.56**^{a}	1.18	1.37	1.05	**1.20**^{b}
Garden pea	1.54	1.05	1.60	**1.40**^{a}	1.21	0.78	1.10	**1.03**^{bc}
Dolichos lablab	1.73	1.76	1.36	**1.62**^{a}	1.69	2.09	1.70	**1.83**^{a}
Maize	0.62	0.78	0.91	**0.77**^{b}	0.71	0.68	0.53	**0.64**^{c}
Fallow	0.86	0.70	0.88	**0.81**^{b}	1.00	0.96	1.10	**1.02**^{bc}
N means (LAI)	**1.38**^{a}	**1.23**^{a}	**1.23**^{a}		**1.15**^{a}	**1.14**^{a}	**1.19**^{a}	

Fallow management means followed by the same letter in the column are not significantly different as per Duncan means separation procedure ($\propto=0.05$)
Nitrogen treatment means followed by the same letter in the row are not significantly different according to the Duncan means separation procedure ($\propto=0.05$)

Table 4.4; The effect of fallow management and inorganic-N treatments on maize DM yields at R2 growth stage in Njoro and Rongai during 1998 cropping season.

	Maize biomass yield at R2 (Mgha^{-1})							
	Njoro				**Rongai**			
	Nitrogen levels (Kg ha^{-1})				**Nitrogen levels (Kg ha^{-1})**			
Fallow management treatments	**0**	**30**	**60**	***Fallow Mgt means***	**0**	**30**	**60**	***Fallow Mgt means***
Chickpea	17.99	15.07	16.64	**16.57^{ab}**	5.80	9.04	13.00	**9.28^{b}**
Field bean	13.95	21.64	13.61	**16.40^{ab}**	6.90	7.04	13.84	**9.26^{b}**
Soybean	19.78	21.20	14.96	**18.64^{ab}**	5.90	7.23	11.86	**8.33^{b}**
Garden pea	17.91	13.30	25.63	**18.95^{ab}**	8.72	8.11	11.35	**9.39^{b}**
Dolichos lablab	26.77	18.85	18.66	**21.43^{a}**	13.68	15.30	15.69	**14.89^{a}**
Maize	12.90	8.81	11.65	**11.12^{b}**	6.25	7.79	8.08	**7.37^{b}**
Fallow	12.38	11.72	13.50	**12.53^{ab}**	7.28	7.79	9.80	**8.29^{b}**
N means (Mgha^{-1})	**17.38^{a}**	**15.80^{a}**	**16.38^{a}**		**7.79^{b}**	**8.90^{ab}**	**11.95^{a}**	

Fallow management means followed by the same letter in the column are not significantly different as per Duncan means separation procedure (α=0.05)
Nitrogen treatment means followed by the same letter in the row are not significantly different according to the Duncan means separation procedure (α=0.05)

4.3.3 Maize grain yield, ear production and grain weight as influenced by fallow management system and applied N fertilizer

There was a sharp drop in maize grain yield in 1999 compared to 1998 cropping seasons (Table 4.5 a and b). In addition to the depressed grain yield in 1999, maize response to treatments was not clearly separable that year. However, in 1998 cropping season, there were large differences in grain yield response to fallow management practices. Maize grain yield following dolichos was notably higher than in maize following weedy fallow and maize monocrop at the two sites. However, response in maize grain yield to the other fallow management treatments were less distinct. Inorganic N application gave mixed results at Njoro, and only large doses of N application (60 kg ha^{-1}) induced marked increases in grain at both sites in 1998 (Table 4.5).

Dolichos increased maize ears per plant at both locations in 1998 (Table 4.6). Maize grain weight was also improved in a legume-maize sequence compared to continuous maize culture and traditional fallow at Rongai in 1998 (Table 4.7). Applied N improved ear number and grain weight at Rongai but not so clearly at Njoro during the same year (Table 4.6 and 4.7).

Table 4.5; Effect of fallow management and applied N fertilizer on maize grain yield (Mg ha^{-1}) at Njoro and Rongai in (a) 1998 and (b) 1999 cropping seasons.

a) Maize grain yield in 1998

	Maize grain yield in 1998 (Mg ha^{-1})							
	Njoro				**Rongai**			
	Nitrogen levels (Kg ha^{-1})				**Nitrogen levels (Kg ha^{-1})**			
Fallow management treatments	**0**	**30**	**60**	***Fallow Mgt means***	**0**	**30**	**60**	***Fallow Mgt means***
Chickpea	5.66	7.20	8.37	**7.08^{ab}**	4.45	4.75	6.38	**5.19^{b}**
Field bean	6.25	5.97	7.12	**6.44^{abc}**	4.05	4.39	7.19	**5.21^{b}**
Soybean	5.84	5.88	8.38	**6.70^{ab}**	4.33	5.26	5.68	**5.09^{bc}**
Garden pea	5.57	5.31	7.23	**6.04^{bc}**	4.28	3.59	4.50	**4.12^{bc}**
Dolichos lablab	6.95	7.74	7.85	**7.51^{a}**	6.32	6.96	7.43	**6.90^{a}**
Maize	4.28	5.33	6.18	**5.26^{cd}**	3.49	2.27	4.55	**3.60^{c}**
Fallow	5.05	2.79	5.75	**4.53^{d}**	3.33	4.49	4.48	**4.10^{bc}**
N means (Mg ha^{-1})	**5.66^{b}**	**5.74^{b}**	**7.27^{a}**		**4.32^{b}**	**4.60^{b}**	**5.74^{a}**	

CV (%) = 16.13 and 29.57 for Njoro and Rongai respectively

Fallow management means followed by the same letter in the column are not significantly different as per Duncan means separation procedure ($\propto$=0.05)

Nitrogen treatment means followed by the same letter in the row are not significantly different according to the Duncan means separation procedure ($\propto$=0.05)

b) Maize grain yield in 1999

Maize grain yield in 1999 (Mgha^{-1})

	Njoro				**Rongai**			
	Nitrogen levels (Kg ha^{-1})				**Nitrogen levels (Kg ha^{-1})**			
Fallow management treatments	**0**	**30**	**60**	***Fallow Mgt means***	**0**	**30**	**60**	***Fallow Mgt means***
Chickpea	2.17	2.11	2.18	**2.15^{a}**	2.73	4.00	4.22	**3.65^{a}**
Field bean	1.78	2.59	3.13	**2.50^{a}**	3.79	2.76	4.07	**3.64^{a}**
Soybean	1.99	2.39	2.08	**2.15^{a}**	3.98	3.57	3.55	**3.66^{a}**
Garden pea	2.58	2.13	2.93	**2.68^{a}**	3.16	1.96	5.01	**3.38^{a}**
Dolichos lablab	2.29	2.32	3.00	**2.57^{a}**	3.10	3.12	5.07	**3.76^{a}**
Maize	2.86	1.21	2.86	**2.31^{a}**	3.23	2.83	3.95	**3.34^{a}**
Fallow	2.34	2.49	2.02	**2.28^{a}**	2.91	3.41	4.22	**3.51^{a}**
N means (Mgha^{-1})	**2.27^{a}**	**2.18^{a}**	**2.60^{a}**		**3.23^{b}**	**3.11^{b}**	**4.30^{a}**	

CV (%) = 34.76 and 39.49 for Njoro and Rongai respectively

Fallow management means followed by the same letter in the column are not significantly different as per Duncan means separation procedure ($\propto$=0.05)
Nitrogen treatment means followed by the same letter in the row are not significantly different according to the Duncan means separation procedure ($\propto$=0.05)

Table 4.6; Maize ears (cobs) as influenced by fallow management and N fertilizer treatment at Njoro and Rongai during 1998 cropping seasons.

	Maize cobs in 1998 (number plant^{-1})							
	Njoro				**Rongai**			
	Nitrogen levels (Kg ha^{-1})				**Nitrogen levels (Kg ha^{-1})**			
Fallow management treatments	**0**	**30**	**60**	***Fallow Mgt means***	**0**	**30**	**60**	***Fallow Mgt means***
Chickpea	1.22	0.99	1.22	**1.14**^{b}	1.00	1.00	1.50	**1.16**^{ab}
Field bean	1.16	1.11	1.11	**1.12**^{b}	1.00	1.00	1.36	**1.12**^{ab}
Soybean	0.99	1.27	1.33	**1.20**^{b}	0.86	1.06	1.06	**1.00**^{b}
Garden pea	1.05	0.94	1.22	**1.07**^{b}	1.10	1.10	1.06	**1.08**^{b}
Dolichos lablab	1.38	1.44	1.44	**1.42**^{a}	1.20	1.23	1.40	**1.27**^{a}
Maize	1.05	1.05	0.99	**1.03**^{b}	1.06	1.00	1.06	**1.04**^{b}
Fallow	1.05	1.05	0.99	**1.03**^{b}	1.00	1.00	1.13	**1.04**^{b}
N means (number plt^{-1})	**1.13**^{a}	**1.12**^{a}	**1.19**^{a}		**1.03**^{b}	**1.05**^{b}	**1.22**^{a}	

CV (%) = 15.48 and 15.27 for Njoro and Rongai respectively

Fallow management means followed by the same letter in the column are not significantly different as per Duncan means separation procedure ($\propto=0.05$)
Nitrogen treatment means followed by the same letter in the row are not significantly different according to the Duncan means separation procedure ($\propto=0.05$)

Table 4.7; Maize grain weight as influenced by fallow management residues and N fertilizer at Rongai.

	Maize 100-grain weight (gms) at Rongai							
	1998				**1999**			
	Nitrogen levels (Kg ha^{-1})				**Nitrogen levels (Kg ha^{-1})**			
Fallow management treatments	**0**	**30**	**60**	***Fallow Mgt means***	**0**	**30**	**60**	***Fallow Mgt means***
Chickpea	36.60	34.69	39.07	**36.78^{a}**	30.44	32.22	31.82	**31.49^{a}**
Field bean	34.30	33.38	39.45	**35.71^{a}**	31.65	37.16	33.00	**33.94^{a}**
Soybean	31.74	36.51	33.28	**33.84^{a}**	36.88	34.47	31.79	**34.06^{a}**
Garden pea	31.78	27.22	40.02	**33.01^{ab}**	31.96	32.48	35.19	**33.21^{a}**
Dolichos lablab	31.93	33.00	40.19	**35.04^{a}**	33.89	33.44	35.11	**34.14^{a}**
Maize	28.10	31.00	27.74	**28.94^{b}**	29.71	32.08	31.80	**31.20^{a}**
Fallow	32.52	30.78	35.38	**32.89^{b}**	27.55	31.84	33.54	**30.97^{a}**
N means (Grain wt gms)	**32.42^{b}**	**32.37^{b}**	**36.45^{a}**		**31.47^{a}**	**33.38^{a}**	**33.18^{a}**	

CV (%) =12.89 and 15.10 for seed weight in 1998 and 1999 respectively

Fallow management means followed by the same letter in the column are not significantly different as per Duncan means separation procedure ($\propto$=0.05)
Nitrogen treatment means followed by the same letter in the row are not significantly different according to the Duncan means separation procedure ($\propto$=0.05)

4.3.4 Weed biomass and species distribution

Maize succeeding the traditional fallow in 1999 cropping season had generally higher weed biomass (Table 4.8). Legume-managed fallow significantly reduced weed biomass at Njoro and Rongai. Among the short-rains crop managed fallows, dolichos gave the lowest weed biomass although this effect was statistically similar to other legume crops.

Perennial weed species were dominant over annual weed types in maize succeeding the natural fallow. Increased weed species were recorded in maize succeeding traditional fallow treatment and reduced in maize following crop-managed especially legume-managed fallow. (Table 4.8). Weed types in maize following legumes were predominantly annuals. In contrast, maize after the traditional fallow harboured both annual and perennial weeds (Table A5.1 and A5.2).

Table 4.8; Above-ground weeds biomass (Mg ha^{-1}) and species per treatment at 4th leaf stage in maize crop at Njoro and Rongai in 1999.

	Weed biomass and species count in maize crop			
	Njoro		Rongai	
Fallow management treatments	**Weed biomass** (Mg ha^{-1})	**Weed species** (No./treat)	**Weed biomass** (Mg ha^{-1})	**Weed species** (No./treat)
Chickpea	0.24^{abc}	2.66^{bc}	0.02^{b}	0.44^{bc}
Field bean	0.16^{bc}	2.44^{bc}	0.03^{b}	0.22^{bc}
Soybean	0.12^{bc}	1.77^{c}	0.00^{b}	0.55^{bc}
Garden pea	0.14^{bc}	3.00^{abc}	0.00^{b}	0.00^{c}
Dolichos lablab	0.09^{c}	2.22^{bc}	0.00^{b}	0.00^{c}
Maize	0.28^{ab}	3.11^{ab}	0.12^{a}	1.22^{b}
Fallow	0.37^{a}	4.00^{a}	0.12^{a}	2.55^{a}

Means followed by the same letter in the column are not significantly different as per Duncan means separation procedure (∝=0.05)

4.4 Discussion

4.4.1 Influence of legume-managed fallow on soil-N and uptake by succeeding maize crop.

Legume-managed fallow during the short-rains season in the Kenya Highlands improved soil nitrogen status for succeeding maize crop in the long-rains cropping season. Soil N was improved in legume-managed fallow against the traditional unmanaged fallow with outstanding performance in dolichos species as observed in the wheat experiment (section 3.4.1). Except for 0-15 cm fraction in 1999 at Njoro, plots preceded by dolichos increased N by 44-87%. Besides soil N determination, the effect of soil N as influenced by incorporated residues was registered by above-ground maize biomass at V6 growth stage. Differences in maize biomass prior to N application at V6 is a result of direct contribution of incorporated residues on soil-N status. In effect, dolichos, chickpea and field bean favoured increases in DM in maize at early growth stage (Table A4.1). It has been widely demonstrated that precursor legumes improve soil N status and hence the performance of succeeding cereals (Oikeh *et al.*, 1998; Maroko *et al.*, 1998; Horst and Hardter,1994; Wortman *et al.*, 1994; Onim *et al.*, 1990; Reddy *et al.*, 1986).

Incorporated organic residue undergo mineralization process whose rate depend on tissue quality particularly polyphenol, lignin and N content as discussed in chapter 3 (Palm 1995; Fox *et al.* 1990;). Frankenberger and Abdelmagid (1985), cited by Fox *et al.* (1990), report that tissue-N concentration is closely correlated with mineralization and that the rate is influenced by lignin concentration. In a study involving forage legumes, Fox *et al.* (1990) and Yamoah *et al.* (1986) observed general tendency for increased mineralization with increased legume N concentration. Palm (1995) reported that multiple analysis points at tissue-N concentration as primary determining factor in initial N release and polyphenol concentration as secondary.

Given the above information, quality of the incorporated organic residue and particularly tissue-N content has direct bearing on soil-N status. This suggests that the difference in soil-N as influenced by different organic residue in this study emanates from tissue-N concentration (Table 2.4) and not biomass quantity incorporated (Table 2.1). For instance, despite large quantities of residue in the weed fallow, its impact on soil-N after incorporation was low compared to dolichos and this is attributed to residue quality.

Subsequently, N uptake by maize crop as determined in vegetative tissue was higher for maize succeeding legumes except garden pea and least for maize preceded by maize and weedy fallow treatments. Nutrient uptake by plants is related to its availability in soil nutrient pool and the difference in legume tissue N and soil N attributed to the fallow practices was discussed earlier (chapter 2). Maize plant is known to accumulate upto 1%N in vegetative tissue and 2% in the grain (Russell, 1988). Maize succeeding dolichos had higher tissue N suggesting improved N supply in soil nutrient pool emanating from the incorporated dolichos residue (Table A4.2). Effect of garden pea was lower than expected because aboveground biomass was destroyed by guinea fowls (Table 2.1). Soil-N greatly influence N uptake by plants as demonstrated by Inorganic-N input which increased grain-N from 1.48% at zero level to 1.64% and 1.69% at 30 and 60kg N ha^{-1} respectively.

4.4.2 Growth and development in maize crop

There was significant effect of fallow management treatments on growth and development of the succeeding maize crop. Owing to soil nutrient effect, especially N, maize succeeding legumes particularly dolichos had increased leaf numbers (Table A4.3). Leaves are important organs for interception of solar radiation and synthesis of photoassimilates. Maize canopy is made up mainly of leaves and a plant that can develop sufficiently large canopy rapidly is capable of better yields (Forbes and Watson, 1992). A good measure of canopy development is leaf area index (LAI) which was shown to be higher for maize succeeding legumes (Table 4.3). A large canopy translates to a higher photoassimilates which are partitioned to various sinks for both growth and development. Forbes and Watson (1992) point out LAI as an important factor determining crop growth rate and predict improved crop yields based on increased LAI. Increased N fertilizer and higher sowing densities are reported as factors encouraging attainment of optimum LAI early and that optimum is 4-5 for cereals (Forbes and Watson, 1992).

Canopy development in maize as influenced by the preceding legume is largely responsible for observed difference in DM yield of maize at grain filling stage (R2) whereby maize after dolichos had better biomass than maize after either weed fallow or maize monocrop (Table 4.4). A check in growth rate as determined by DM accumulation between V6 and R2 growth stages confirms relatively higher growth rate in maize succeeding legumes especially dolichos (Table 4.2).

Observed difference in DM yield and DM accumulation rate between Njoro and Rongai is probably due to environmental growing conditions mainly temperature (Fig. A3.1 and A3.2). Under relatively low temperature as is the case with Njoro, maize grows slowly and takes longer time from one stage to the next. Maize took 188 days to physiological maturity at Njoro against 167 days for Rongai in 1998 cropping season. Temperature has been identified as a key factor determining length of crop growth (Forbes and Watson, 1992; Squire, 1990). Increased growing days has been shown to increase yields (Forbes and Watson, 1992). Delayed crop maturity allow the plants more time to photosynthesize thereby increasing assimilates available for partitioning to various sinks and particularly, to the competitive ears for grain filling (Squire, 1990). Though relatively high temperatures stimulate growth, it could result in higher energy drain in growing plants through cooling and manufacture of structural proteins necessary under heat stress conditions leading to low yield. Temperature was therefore key feature responsible for the differences in DM and subsequent maize grain yield (section 4.4.3) at the two locations.

4.4.3 Grain yield in maize

Grain yield in maize following legumes was higher than a preceding weed fallow or maize monocrop. Maize yield after legumes was 33-65% higher than maize following weed fallow and 14-42% higher than that from a previous maize plots at Njoro while at Rongai, maize yield following legumes gave 24-68% higher yield compared to weed fallow and 14-91 % higher than maize monocrop (Table 4.5). Maize succeeding dolichos gave outstanding grain yield at the two sites. There was observed significant yield increase with N fertitlizer input at 60 kg N ha^{-1} giving 28% and 32% higher yield compared to zero N at Njoro and Rongai respectively. The results agree with studies elsewhere (Oikeh *et al.*, 1998; Kwesiga and Coe, 1994; Bundy *et al.*,1993; Onim *et al.*, 1990). Oikeh *et al.* (1998) observed a 20 and 24 % yield increase where maize was grown after *Stylosanthes hamata* and *Glycine max* respectively compared to maize after a maize monocrop despite removal of aboveground biomass of the legumes. Maize yield during 1999 cropping season showed no response unlike 1998 due to unusually dry weather condition (Figs. A3.1 and A3.2)

Higher grain yield was a result of increase in soil N which had profound effect on maize ear numbers and grain weight. Maize succeeding dolichos, chickpea and field bean showed increased cobs per plant ranging from 1.12-1.14 against 1.03 and 1.04 in a preceding weed fallow and maize plot. Grain weight ranged between 33 and 36 g under managed fallows and 28 and 32 g in maize monocrop and weed fallow plot. This further confirms the influence of fallow management on maize yield components which have direct effect on grain yield. Onim *et al.*(1990) observed that Sesbania and Leucaena green manure improved both cobs and grain yield in maize and attributed this to increased soil N by the two fodder legumes. In studies conducted by Oikeh *et al.*(1998), Horst and Hardter (1994), Tian *et al.* (1994) it emerges that soil N plays a key role in improving maize yield in a legume-maize sequence and that soil N is a direct influence of the quality of residues in plots preceding maize crop. This study indicates that growing legumes during the short-rains season can lead to higher maize grain yield during the long-rains season even with absence of inorganic-N. In the absence of N fertilizer, maize succeeding dolichos, gave 20-40% yield higher than maize after weed fallow and 12-38% higher than a continuous maize. Maize after chickpea and field bean gave similar or better yields at zero and/or at 30 kg N ha^{-1} compared to maize after weed fallow and maize monocrop.

The findings in this study may translate into financial savings by farmers on incurred expenses on N fertilizer input. In addition, maize grain yields would surge closer to the target 7 ton ha^{-1} (KARI, 1992; KARI & MIAC, 1993) if a combination of legume and N fertilizer is chosen.

4.4.4 Weed biomass and weed species distribution

Crop-managed fallow weakened invasion of weeds in a succeeding maize crop. The traditional fallow break provides an opportunity for weeds to complete their growth cycles and hence increase seed bank with subsequent weed infestation in succeeding crops.

Increased weed biomass in unmanaged against crop-managed fallow (Table 4.8) could be attributed to increased weed seed reservoir and hence strengthened regenerative capacity during fallow break. In a maize-groundnut rotation Mloza-Banda (1997) showed that rotational cropping essentially reduced or changed weed species composition and density attributed to production practices unfavourable for weed growth (Mwaja and Masiunas, 1997). In addition, managed fallow essentially reduced weed species composition in the succeeding maize crop. Crops grown during short-rains season acted as cover crops. For instance, dolichos and garden pea have sprawling growth habit, forming a dense canopy on ground surface which may have effectively reduced light availability for weed seeds thereby inhibiting them from germinating (Wilson, 1988; Egley and Duke, 1985).

In the absence of adequate intervention measures, crop yields would be substantially depressed (see section 3.4.3). The impact of weeds on crop yields confounded by declining soil fertility therefore has enormous deleterious potential on the test crop. The effect of legume-managed fallow substantially reduced weed incidence in succeeding crop which could consequently lessen the need for laborious weed management practices.

4.5. References

Altieri, M. A. and M. Liebman. 1986. Insect, weed and plant disease management in multiple cropping systems. In: Charles A. Francis (ed.) Multiple Cropping System. Macmillan Publishers, NY. 183-218.

Bundy, L.G., T.W. Andraski and R.P. Wolkowski. 1993. Nitrogen credits in soybean-corn crop sequences on three soils. Agronomy Journal. 83: 1061-1067.

Egley, G.H. and Duke, S.O. 1985. Physiology of weed seed dormancy and germination. In: Stephen O. Duke (ed.) Weed Physiology V.II; Reproduction and Ecophysiology. CRC press, Inc.

Forbes, J.C. and R.D. Watson. 1992. Crop production and yield *In*: Plants in Agriculture. University Press, Cambridge, USA. 264-268.

Fox, R.H., R.J.K. Myers and I. Vallis. 1990. The nitrogen mineralization rate of legume residues in soil as influenced by their polypheneol, lignin, and nitrogen content. Plant and Soil 129: 251-259.

GOK. 1994. Sessional paper No. 2 of 1994 on National Food Policy for Renewed Growth. Government Printers, Nairobi.

Guto, S.N. 1997. Effects of chickpea (*Cicer arietinum* cv. Kaburi) and common beans (*Phaseolus vulgaris* L. cv. Rose coco) on wheat performance and soil fertility in a legume-wheat cropping sequence. MSc thesis, Egerton University, Njoro, Kenya.

Handayanto, E., Y. Nuraini, P. purnomosidi, M. Hanegraaf, G. Agterberg, J. Hassink and M. van Noordwijk. 1992. Decomposition rates of legume residues and N-mineralization in an ultisol in Lampung. AGRIVITA. 15(1):75-86.

Horst, W.J. and R. Hardter. 1994. Rotation of Maize with cowpea improves yield and nutrient use of maize compared to maize monocropping in an alfisol in the northern Guinea savanna of Ghana. Plant and Soil. 160: 171-184.

Jaestzold, R. and H. Schmidt. 1983. Farm management hand book of Kenya. Vol. II/B Central Kenya. Ministry of Agriculture, Kenya in Cooporation with German Agricultural Team (GAT) of German Agency of Technical Cooperation (GTZ).

KARI. 1992. Improve and sustain maize production through adoption of known technologies. Information Bulletin, Kenya Agricultural Research institute, Nairobi, Kenya.

KARI. 1997. Crop production guidelines for wheat, oilcrops and horticulture. Arama, P.F., J.K. Wanjama, F. Kiriswa and P.K. Macharia. (eds). National Plant Breeding Research Centre, Njoro.

KARI and MIAC. 1993. Strategic plan for Cereals in Kenya (1993-2013). Kenya Agricultural Research Institute, Nairobi, Kenya.

Kwesiga, F.and R. Coe. 1994. The effect of short rotation *Sesbania sesban* planted fallows on maize yield. Forest Ecology and Management. 64:199-208.

Maroko, J.B., R.J. Buresh and P.C. Smithson. 1998. Soil nitrogen availability as affected by fallow-maize systems on two soils in Kenya. Biol Fert. 26:229-234.

Mloza-Banda, H.R. 1997. Changes in weed species composition in maize-based cropping system in central Malawi. In: The 16th East African biennial weed science conference proceedings, Kampala, 15-18 Sept. 1997. 71-79.

Muriuki, E.M. 1998. Report of the ECAMAW working group meeting on soil fertility issues in maize and wheat based system in Eastern and Central Africa. 15-19th November 1998, Mombasa Kenya.

Mwaja, V. and J. Masiunas. 1997. Sustainable weed management systems in agriculture: A review. In: The 16th East African biennial weed science conference proceedings, Kampala, 15-18 Sept. 1997. 21-32.

Norman, J.M. and G.S. Campbell. 1989. Cannopy structure. pp 301-326. In: Pearcy R.W., J.Ehleringer, H.A. Mooney and P.W. Rundell (eds). Plant Physiological Ecology: Field Methods and Instrumentation. Chapman and Hall.

Oikeh, S.O., V.O. Chude, R.J. Carsky, G.K. Weber and W.J. Horst. 1998. Legume rotation in the moist tropical savanna: managing soil nitrogen dynamics and cereal yields in farmers' fields. Experimental Agriculture. 34: 73-83.

Okalebo J.R., K.W. Gathua and P.L. Woomer. 1993. Laboratory Methods of Soil and plant Analysis: A working manual. Tropical soil biology and fertility programme. Nairobi, Kenya.

Onim, I.F.M., M. Mathuva, K. Otieno and H.A. Fitzhugh. 1990. Soil fertility changes and response of maize and beans to green manures of Leucaena, Sesbania and Pigeonpea. Agroforestry systems. 12: 197-215.

Onwonga, R.N. 1997. Effect of chickpea incorporation on soil nutrient status and wheat grain yield in a wheat-chickpea rotation. MSc thesis, Egerton University, Njoro, Kenya.

Palm C.A. 1995. Contribution of agroforestry trees to nutrient requirements of intercropped plants. Tropical Soil Biology and Fertility Programme, Nairobi, Kenya. Agroforestry System, Kluwer Academic Publishers, Netherlands. v. 30:105-124.

Page, A.L., R.H. Miller and D.R. Keeney. 1982. Methods of soil analysis. Part 2; Chemical and microbiological properties. American Society of Agronomy, USA.

Reddy K.C., A.R. Soffes and G.M. Prine. 1986. Tropical legumes for green manure. I. Nitrogen production and the effects on succeeding crop yields. Agronomy Journal. 78(1): 1-4.

Rheenen, H.A.V., A. Tullu, A.I.S. Mohamed and P. Omanga. 1991. Growing chickpea in Eastern Africa. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Patancheru, A.P. 504 324, India: ICRISAT.

Ritchie, W.S., J.J. Hanway and G.O. Benson. 1986. How a corn plant develops. Special report No.48. Extension service, Ames Iowa.

Russell's E.W. 1988. Mineral nutrition of crop plants. In: Alan Wild (ed.) Soil conditions and plant growth. Longman Group UK Ltd. 69-112.

SAS institute. 1996. SAS for windows 6.12. Cary NC USA.

Steel, R.G.D., J.H. Torrie and D. A. Dickey. 1997. Principles and practices of statistics, a biometrical approach. McGraw-Hill Companies, Inc.

Squire, G.R. 1990. Dry matter production and solar radiation. In: The physiology of Tropical crop production. CAB International, Wallingford, UK. 73-99.

Tanner, D.G., Z. Yilma, L. Zewdie and G. Gebru. 1994. Potential for cereal-based double cropping in Bale region of South Eastern Ethiopia. African Crop Science Journal. 2:135-143.

Tian, G., B.T. Kang and L. Brussaard. 1994. Mulching effect of plant residues with chemically contrasting compositions on maize growth and nutrients accumulation. International Institute of Tropical Agriculture (IITA) Research No 9: 7-11.

Wilson, R.G. 1988. Biology of weed seeds in the soil. In: Altieri M. A. and Matt Liebman. Weed Management in Agroecosytems: Ecological Approaches. CRC Press.

World Bank. 1998. World Development Indicators. Washington D. C., USA.

Wortmann, C.S., M. Isabirye and S. Musa. 1994. *Crotalaria ochroleuca* as a green manure crop in Uganda. African Crop Science Journal. 2:55-61.

Yamoah, C.F., A.A. Agboola and K. Mulongoy. 1986. Decomposition, nitrogen release and weed control by prunings of selected alley cropping shrubs. Agroforestry Systems. 4:239-246.

Chapter Five

Summary, Conclusion and Recommendation

5.0 Summary

Legume-managed fallow improved grain yield of succeeding wheat and maize crops against the traditional practice. The positive effect of dolichos on the cereals performance was much more pronounced among the legume species used and this was attributed to good quality residue as discussed earlier (chapters 3 and 4). Dolichos nodulated readily and its possibility of having deep root system could have contributed to enhanced nutrient uptake thereby improving residue quality. Though the effects of chickpea, field bean, garden pea and soybean were not quite as distinct, their impact on subsequent cereal crop was generally positive. The difference amongst legumes could be due to their tissue mineralization rates which was not determined.

The grain yield in maize surged closer to the national target of 7 tons ha^{-1} following legume-managed fallow. However, wheat yields improved slightly above the national average but still far below the potential 4 ton ha^{-1} thus suggesting other factors besides mineralized-N, influencing wheat grain yield.

This study has shown that the low cereal yields currently experienced in the Kenya Highlands can be improved through management of the traditional short-rains season fallow. The October-December period between successive cereal cropping in the Kenya Highlands can be managed effectively with legumes. Dolichos and chickpea emerged as better adapted to the short-rains season compared to field bean, garden pea and soybean. Their adaptation is probably attributed to their tolerance to water stress during the season which could be due to possession of their deep root system capable of harvesting water from lower soil horizons. Though biomass gain from legume-managed fallow was relatively low compared to both weedy and cereal fallow, quality of the biomass was better with respect to the N content and C/N ratio. The legume biomass quality appears to be a central factor in observed improved grain yield in sequentially grown cereals. The legume biomass quality appears to be a central factor in observed improved grain yields in sequentially grown cereals.

The legume-managed fallows improved the soil NO_3^- status mainly through mineralization of their incorporated residues which led to improved yields of succeeding cereals. Among the evaluated legumes, dolichos had notably low biomass but with relatively high tissue N and it significantly improved soil N status. Wheat and maize crop yields were subsequently high following dolichos-managed fallow. Wheat succeeding dolichos gave 2.7 ton against 2.1 ton ha^{-1} for wheat preceded by weedy fallow. Maize after dolichos gave an average grain yield of 6.6 tons ha^{-1} without N input and about 5 tons ha^{-1} following unmanaged fallow but with 60 kg N ha^{-1}. This reflected an increase of 40% grain yield in maize after dolichos treated with zero inorganic N compared to grain yield in maize following traditional weedy fallow with recommended supply of 60 kg N ha^{-1}. The observed increase in yield of succeeding cereal was a result of good quality and readily mineralizable dolichos residue which improved soil NO_3^- for plant uptake.

Besides improvement in yield of the succeeding cereal, legume-managed fallows reduced weed biomass and species in subsequent cropping with notable reduction in perennial weeds. Among the reduced perennial weeds were *Pennisetum clandestinum* and *Digitaria scalarum.* Dolichos and garden pea produced dense canopy that smothered weeds. They acted as a physical barrier against sprouting weeds and inhibited germination of weed seed by attenuating incoming radiation.

5.1 Conclusion and recommendation

The management of the short-rains season fallow in the Kenya Highlands is a viable practice which is set to improve succeeding cereal yields in the region.

(a) The following are conclusions drawn from this study;

(i) Legume managed fallows, in contrast to weedy fallows and cereal monoculture were generally associated with improved grain yields of succeeding wheat and maize. The effect of legumes on the cereals grain yield was more pronounced in maize than in wheat.

(ii) dolichos is better adapted legume to the short-rains season and hence is the most promising legume species for the fallow management,

(iii) dolichos-managed fallow improves soil-N ($NO_3^- + NH_4^+$) status following incorporation of the crop's residues and thereby increased the yield of the succeeding wheat and maize crop(s). Considering adaptability to the semi-dry conditions in the short-rains season and the contribution to soil N for the succeeding cereal, dolichos is a better alternative for the fallow management. Besides dolichos, chickpea could be an ideal legume for small scale farmers in cooler regions such as Njoro because of additional benefit of seed yield and the potential for survival in residual moisture,

(iv) legume-managed fallow reduce weed density in the succeeding cereal crop,

(v) the study has demonstrated that site differences with regard to residual soil nitrogen, ambient temperatures and soil moisture availability had large effects on crop responses to treatments. Thus N effects on wheat grain yields were only marginally noticed in Njoro compared to Rongai. On the other hand the 1999 drought more severely masked both crop responses in Rongai.

(b) However, there has been limitations in this study which should be focused on for further research and include the following;

i) Mineralization of crop residue vary with species as discussed earlier in chapters 3 and 4. Owing to the scope of this work, it was not possible to undertake mineralization studies for the fallow management species which is necessary for synchronizing optimum nutrient release through mineralization of incorporated organic residues with the succeeding crop demand. Mineralization studies on the potential fallow management legume residues in the Kenya Highlands is recommended.

ii) Quantity of light attenuated by canopies of the legumes which could be a factor influencing emergence of weed seeds as discussed in chapters 3 and 4 was not done because of resource limitation, and its characterisation studies should be persued.

(iii) The root systems in the legumes which was mentioned as possible contrasting factor in the legume tolerance to the semi-dry condition during the short-rains season was not explored. Study on rooting depth and spread especially for dolichos and chickpea is needed to ascertain its role in the legume tolerance to drought conditions.

(iv) Full characterisation of chickpea, which is a newly introduced crop in this region is required. For this study the chickpea cultivar used was simply one that had been used and shown to be adaptable mainly in the Eastern province of Kenya. Specifically there is an urgent need to establish why chickpea nodulates so little in the environment of study even when inoculated with specific strain of Rhizobia.

(v) A cost-benefit analysis of the legume-cereal sequential cropping was not done yet it is crucial for economic comparison of available options to the farmers. There is therefore need to undertake a parallel study on economics involved in the alternative cropping approaches in this study.

Appendix 1: Soil base data and soil moisture changes at the experiment sites

Table A1.1; Soil chemical characteristic for Njoro and Rongai experiments site

	Njoro		Rongai	
	0-15 cm	15-30 cm	0-15 cm	15-30cm
Soil pH (H_2O)	6.10	5.70	5.90	5.70
Carbon (%C)	3.18	2.19	2.08	0.78
Total N (%N)	0.28	0.25	0.14	0.08
Phosphorous (ppm)	25.00	20.00	0.11	0.22
Organic matter	5.48	3.78	3.59	1.35
C/N ratio	11.00	8.80	14.86	9.28
C.E.C	23.60	21.40	-	-

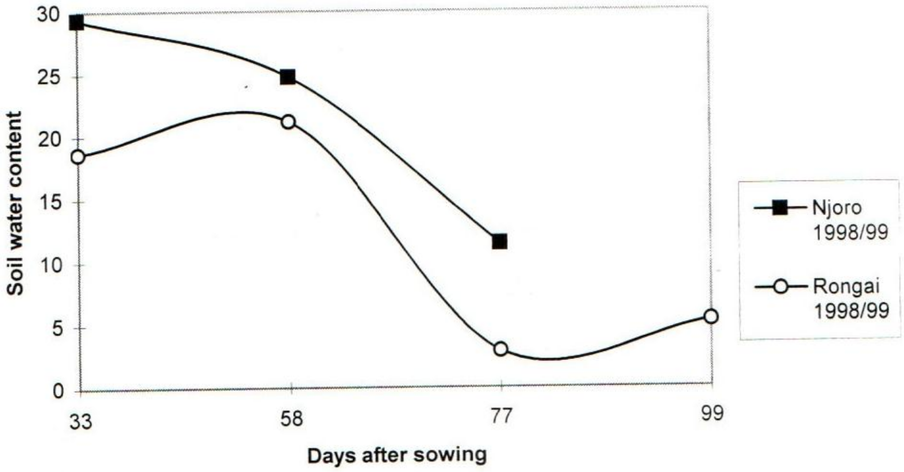

Fig. A1.1; Soil moisture content at Njoro and Rongai during the 1998/99 short-rains cropping season.

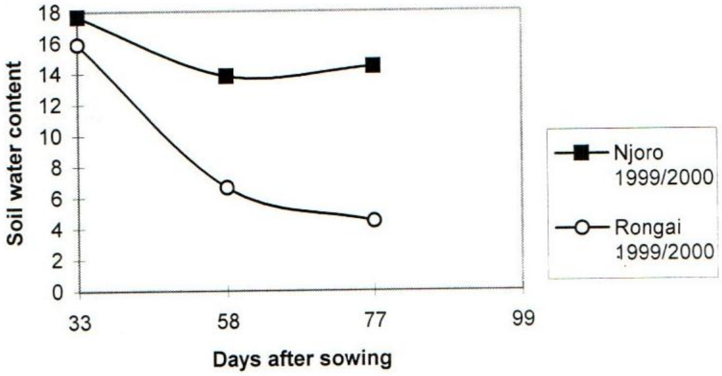

Fig. A1.2; Soil moisture content at Njoro and Rongai during the 1999/2000 short-rains cropping season.

Appendix 2: Short-rains crops stand count, rainfall and temperature data

Table A2.1; Stand count for the fallow management crops expressed as per cent of emerged seedlings at flowering and at harvest indicating crop survival rate at Njoro and Rongai in 1999/2000.

a) Njoro

F-management treatments	Wheat experiment: Crop stand count as per cent of emerged seedlings		Maize experiment: Crop stand count as per cent of emerged seedlings	
	At Flowering	At Harvest	At Flowering	At Harvest
Chickpea	100^{a}	83.9^{a}	100^{a}	91.9^{a}
Field bean	100^{a}	54.4^{b}	100^{a}	53.2^{b}
Soybean	100^{a}	66.6^{b}	100^{a}	78.3^{a}
Garden pea	100^{a}	84.79^{a}	100^{a}	83.5^{a}
Dolichos lab lab	100^{a}	94.58^{a}	100^{a}	90.0^{a}
Maize	-	-	100^{a}	89.8^{a}
Wheat	$100^{a\tau}$	94.8^{a}	-	-

b) Rongai

F-management treatments	Wheat experiment: Crop stand count as per cent of emerged seedlings		Maize experiment: Crop stand count as per cent of emerged seedlings	
	At Flowering	At Harvest	At Flowering	At Harvest
Chickpea	99.0^{a}	31.9^{bc}	98.7^{a}	36.9^{b}
Field bean	99.3^{a}	24.4^{cd}	98.8^{a}	27.9^{bc}
Soybean	98.9^{a}	55.3^{b}	97.6^{a}	48.5^{b}
Garden pea	98.4^{a}	0.0^{d}	98.4^{a}	6.3^{c}
Dolichos lab lab	99.1^{a}	87.1^{a}	99.3^{a}	88.9^{a}
Maize	-	-	99.4^{a}	27.1^{bc}
Wheat	$99.7^{a\tau}$	$55.6^{b\tau}$	-	-

Means followed by the same letter in the column are not significantly different as per Duncan means separation procedure ($\propto=0.05$)

[τ] Relative score for wheat stand based on visual observation

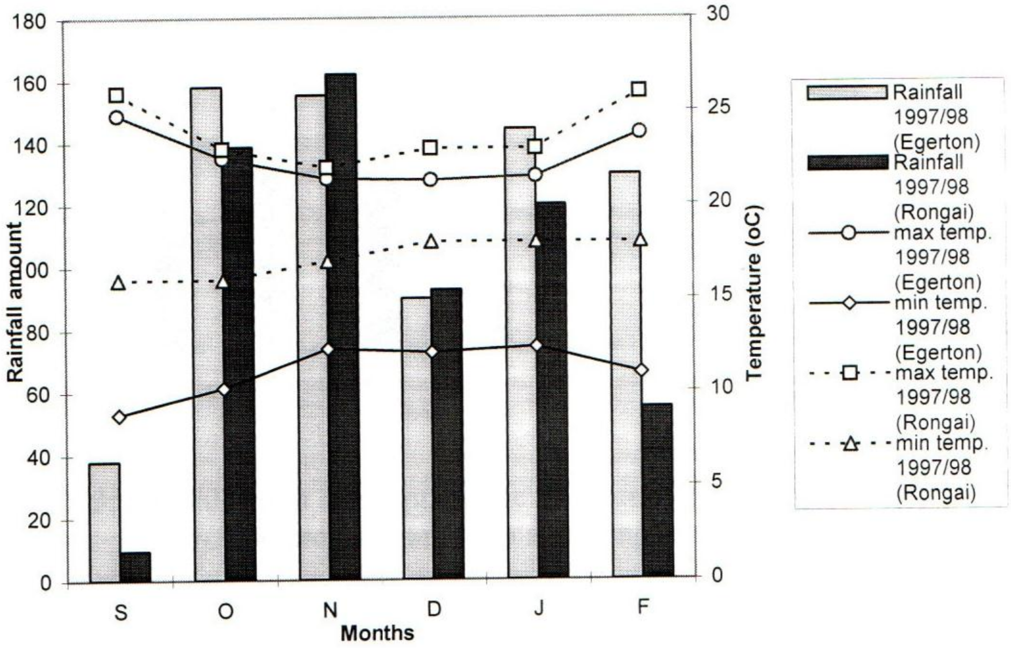

Fig.A2.1; Rainfall (mm) and temperature (°C) during the short-rains season in 1997/98 cropping at Njoro and Rongai.

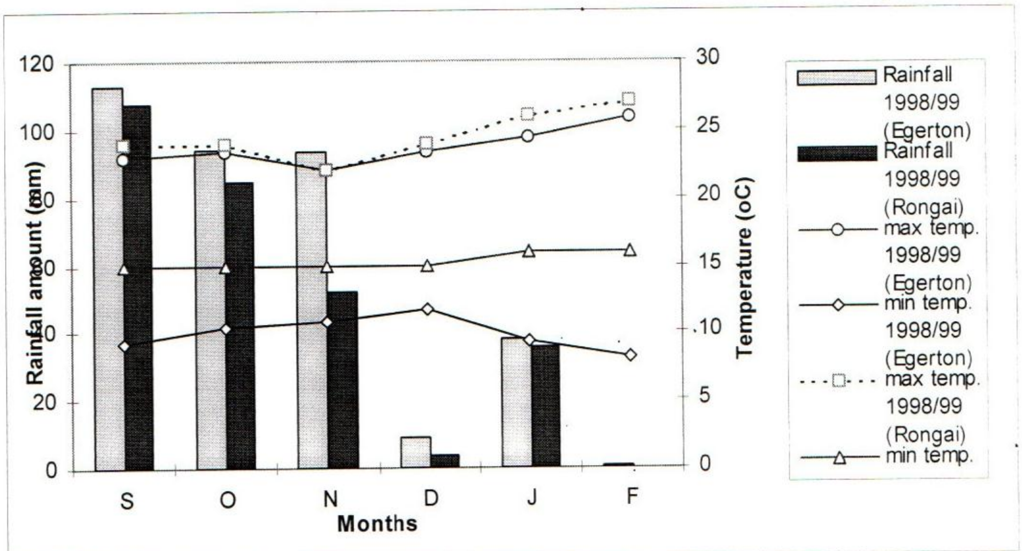

Fig.A2.2; Rainfall (mm) and temperature (°C) during the short-rains season in 1998/99cropping at Njoro and Rongai.

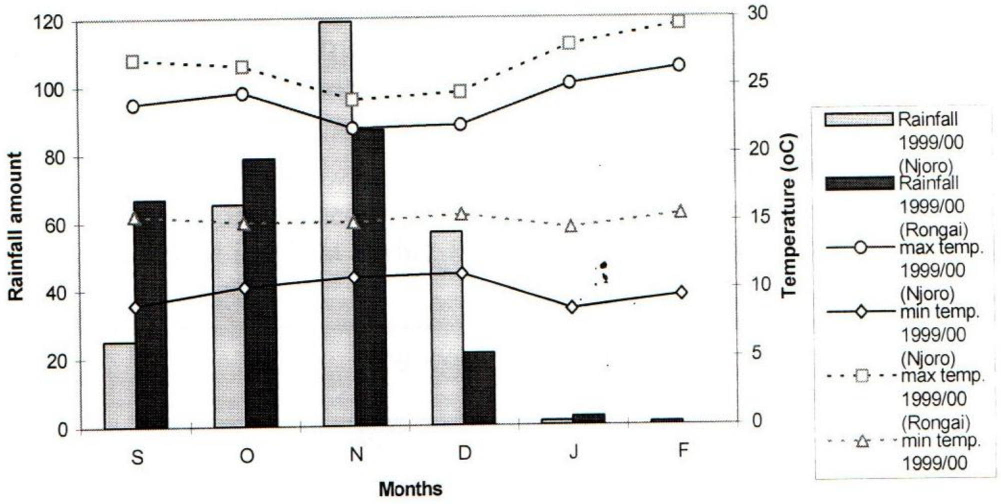

Fig.A2.3; Rainfall (mm) and temperature (°C) during the short-rains season in 1999/2000 cropping at Njoro and Rongai.

Appendix 3: Additional wheat data, rainfall and temperature for the long rains season

Table A3.1; Effect of fallow management treatments and applied N on growth rate as determined by DM accumulation between tillering and heading in wheat during 1998 cropping season.

	Njoro				**Rongai**			
	DM accumulation			**in**	**wheat (gms/day)**			
	Nitrogen levels (Kg ha^{-1})				**Nitrogen levels (Kg ha^{-1})**			
Fallow Management treatments	**0**	**30**	**60**	*F- Mgt Means*	**0**	**30**	**60**	*F-Mgt means*
Chickpea	15.19	7.75	11.63	**11.52**^{ab}	4.18	5.68	4.93	**4.93**^{c}
Field bean	10.51	21.24	23.47	**18.41**^{a}	5.22	15.23	9.85	**10.10**^{ab}
Soybean	12.21	8.99	19.07	**13.57**^{ab}	5.59	8.95	6.47	**7.01**^{bc}
Garden pea	13.28	10.88	10.40	**11.52**^{ab}	7.61	7.62	9.14	**8.12**^{abc}
Dolichos lablab	17.19	19.97	12.87	**17.15**^{ab}	5.36	11.87	17.92	**11.72**^{a}
Wheat	14.79	15.37	8.00	**12.39**^{ab}	4.72	6.45	9.92	**7.03**^{bc}
Fallow	8.88	9.84	15.75	**10.96**^{b}	7.19	8.98	8.01	**8.06**^{abc}
N Means (gms/days)	**13.20**^{a}	**13.34**^{a}	**13.39**^{a}		**5.70**^{b}	**9.26**^{a}	**9.46**^{a}	

Fallow management means followed by the same letter in the column are not significantly different as per Duncan means separation procedure (∝=0.05)
Nitrogen treatment means followed by the same letter in the row are not significantly different according to the Duncan means separation procedure (∝=0.05)

Table A3.2; Effect of fallow management treatments and Inorganic-N application on tiller counts (tillers/plant) in wheat at Njoro and Rongai in 1998 cropping season.

Fallow Management treatments	**Njoro**				**Rongai**			
	Tillers per plant							
	Nitrogen levels (Kg ha^{-1})			***F- Mgt Means***	**Nitrogen levels (Kg ha^{-1})**			***F-Mgt means***
	0	**30**	**60**		**0**	**30**	**60**	
Chickpea	4.22	5.05	4.83	**4.70**^{a}	2.11	3.16	2.61	**2.62**^{bc}
Field bean	3.72	3.16	3.94	**3.61**^{b}	2.22	2.55	2.50	**2.42**^{c}
Soybean	3.94	4.61	3.66	**4.07**^{ab}	2.77	3.55	2.55	**2.96**^{b}
Garden pea	3.83	3.44	3.83	**3.70**^{b}	2.66	3.00	3.11	**2.92**^{b}
Dolichos lablab	4.72	5.38	4.44	**4.85**^{a}	3.38	3.66	4.00	**3.68**^{a}
Wheat	4.33	4.50	4.27	**4.37**^{ab}	2.05	2.44	2.66	**2.38**^{c}
Fallow	4.05	4.05	3.22	**3.77**^{b}	1.50	1.61	1.83	**1.64**^{d}
N Means (Tillers /plt)	**4.11**^{a}	**4.31**^{a}	**4.03**^{a}		**2.38**^{b}	**2.85**^{a}	**2.75**^{a}	

Fallow management means followed by the same letter in the column are not significantly different as per Duncan means separation procedure (α=0.05)

Nitrogen treatment means followed by the same letter in the row are not significantly different according to the Duncan means separation procedure (α=0.05)

Table A3.3; The effect of fallow management treatment on number of spikelets in the succeeding wheat crop at Njoro and Rongai for the 1998 crop.

Fallow Management treatments	**Njoro**				**Rongai**			
			Spikelets	**per**	**spike**			
	Nitrogen levels (Kg ha^{-1})			*F- Mgt Means*	**Nitrogen levels (Kg ha^{-1})**			*F-Mgt means*
	0	**30**	**60**		**0**	**30**	**60**	
Chickpea	18.58	18.61	18.55	**18.58**^{abc}	15.83	15.83	17.11	**16.31**^{a}
Field bean	18.41	19.11	18.25	**18.66**^{ab}	14.83	17.38	15.33	**16.07**^{a}
Soybean	19.33	18.55	17.50	**18.64**^{ab}	15.83	16.08	17.33	**16.45**^{a}
Garden pea	18.58	17.88	20.08	**18.71**^{ab}	16.83	17.11	17.44	**17.13**^{a}
Dolichos lablab	17.50	19.44	19.83	**19.33**^{a}	17.16	16.66	17.00	**16.97**^{a}
Wheat	17.67	18.83	17.11	**17.89**^{bc}	16.83	15.77	15.22	**15.94**^{a}
Fallow	17.17	16.41	17.94	**17.30**^{c}	17.58	15.44	15.22	**15.89**^{a}
N Means (Spikelets)	**18.31**^{a}	**18.50**^{a}	**18.50**^{a}		**16.43**^{a}	**16.35**^{a}	**16.43**^{a}	

Fallow management means followed by the same letter in the column are not significantly different as per Duncan means separation procedure ($\alpha=0.05$)
Nitrogen treatment means followed by the same letter in the row are not significantly different according to the Duncan means separation procedure ($\alpha=0.05$)

Table A3.4; Effect of fallow management treatments on the 100-seed weight of the succeeding wheat crop in 1998 crop.

	Njoro				**Rongai**			
	100-seed weight (gms)							
	Nitrogen levels (Kg ha^{-1})				**Nitrogen levels (Kg ha^{-1})**			
Fallow Management treatments	**0**	**30**	**60**	*F- Mgt Means*	**0**	**30**	**60**	*F-Mgt means*
Chickpea	5.01	5.20	4.97	**5.06^{a}**	4.42	4.25	3.79	**4.15^{a}**
Field bean	5.13	4.90	4.92	**4.96^{a}**	4.43	4.10	3.86	**4.13^{a}**
Soybean	4.76	4.62	4.95	**4.78^{a}**	4.06	4.32	3.88	**4.09^{a}**
Garden pea	4.78	4.18	5.04	**4.65^{a}**	4.56	4.20	4.07	**4.27^{a}**
Dolichos lablab	4.64	4.50	4.74	**4.63^{a}**	4.36	4.25	4.12	**4.24^{a}**
Wheat	4.74	4.99	4.72	**4.82^{a}**	4.04	4.22	4.26	**4.17^{a}**
Fallow	4.97	4.75	4.44	**4.63^{a}**	4.26	4.14	4.37	**4.25^{a}**
N Means (Seed wt gms)	**4.83^{a}**	**4.73^{a}**	**4.82^{a}**		**4.30^{a}**	**4.21^{ab}**	**4.05^{b}**	

Fallow management means followed by the same letter in the column are not significantly different as per Duncan means separation procedure ($\propto$=0.05)
Nitrogen treatment means followed by the same letter in the row are not significantly different according to the Duncan means separation procedure ($\propto$=0.05)

Table A3.5; Effect of fallow management treatments and N fertilizer on per cent N in vegetative tissue and grain of wheat at physiological maturity at the two locations in 1998 cropping season

(a) Vegetative tissue N (%)

	Njoro				**Rongai**			
	Vegetative tissue N (%) in wheat							
	Nitrogen levels (Kg ha^{-1})			*F- Mgt Means*	**Nitrogen levels (Kg ha^{-1})**			*F-Mgt means*
Fallow Management treatments	**0**	**30**	**60**		**0**	**30**	**60**	
Chickpea	0.62	0.80	0.96	**0.81**^{abc}	0.58	0.80	0.93	**0.75**^{a}
Field bean	0.48	0.72	0.76	**0.70**^{cd}	0.80	0.77	0.88	**0.82**^{a}
Soybean	1.00	0.96	0.95	**0.97**^{ab}	0.82	0.71	0.85	**0.79**^{a}
Garden pea	0.61	0.85	0.79	**0.76**^{bcd}	0.54	0.93	0.96	**0.81**^{a}
Dolichos lablab	0.97	0.94	1.05	**0.99**^{a}	0.78	0.90	0.80	**0.83**^{a}
Wheat	0.76	0.74	0.74	**0.74**^{cd}	0.64	0.64	0.87	**0.73**^{a}
Fallow	-	0.57	0.56	**0.57**^{d}	0.61	0.62	0.69	**0.65**^{a}
N Means (%N)	**0.76**^{a}	**0.81**^{a}	**0.84**^{a}		**0.69**^{b}	**0.77**^{ab}	**0.85**^{a}	

Fallow management means followed by the same letter in the column are not significantly different as per Duncan means separation procedure ($\propto=0.05$)
Nitrogen treatment means followed by the same letter in the row are not significantly different according to the Duncan means separation procedure ($\propto=0.05$)

b) Grain N (%)

	Njoro				Rongai			
	Grain N (%) in wheat							
	Nitrogen levels (Kg ha^{-1})				**Nitrogen levels (Kg ha^{-1})**			
Fallow Management treatments	**0**	**30**	**60**	*F- Mgt Means*	**0**	**30**	**60**	*F-Mgt means*
Chickpea	2.62	2.59	2.81	**2.68**^{b}	2.40	2.85	2.79	**2.68**^{ab}
Field bean	2.22	2.71	3.02	**2.70**^{b}	2.77	2.82	2.80	**2.79**^{a}
Soybean	2.75	3.10	2.70	**2.86**^{ab}	2.63	2.75	2.66	**2.68**^{ab}
Garden pea	2.62	2.91	2.63	**2.75**^{b}	2.33	2.74	3.03	**2.70**^{ab}
Dolichos lablab	2.91	3.08	3.02	**3.03**^{a}	2.74	2.77	2.71	**2.74**^{a}
Wheat	2.86	2.67	2.88	**2.80**^{ab}	2.50	2.51	2.51	**2.51**^{b}
Fallow	2.73	2.71	2.86	**2.79**^{ab}	2.65	2.61	2.59	**2.61**^{ab}
N Means (%N)	**2.65**^{b}	**2.83**^{a}	**2.86**^{a}		**2.57**^{b}	**2.72**^{a}	**2.73**^{a}	

CV (%) ; Vegetative tissue N =22.39 (Njoro), 21.76 (Rongai) and Grain N = 8.49 (Njoro), 7.57 (Rongai)

Fallow management means followed by the same letter in the column are not significantly different as per Duncan means separation procedure ($\propto$=0.05)
Nitrogen treatment means followed by the same letter in the row are not significantly different according to the Duncan means separation procedure ($\propto$=0.05)

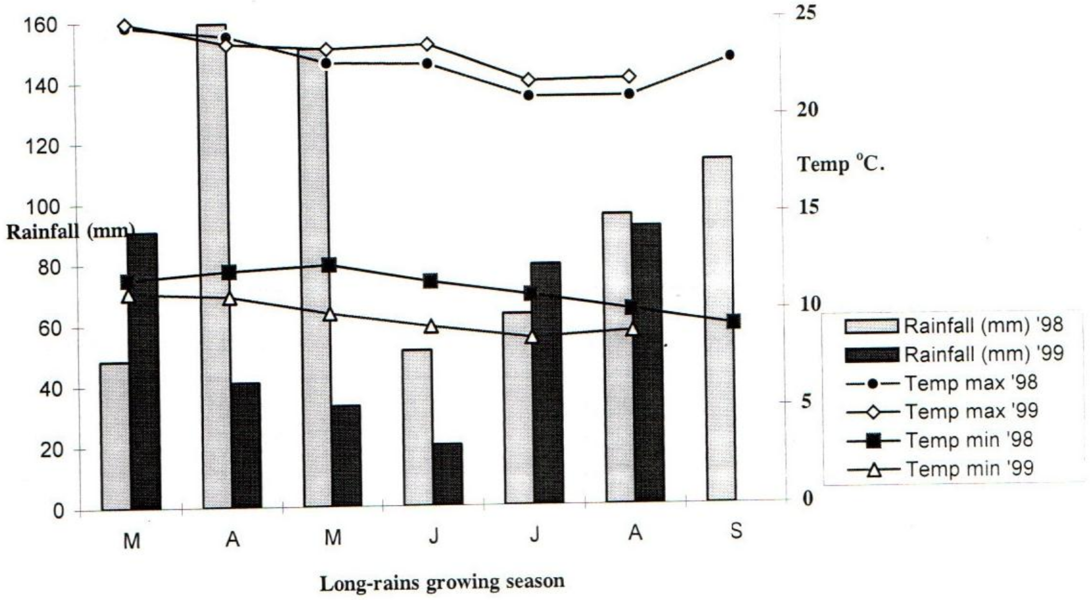

Fig. A3.1; Rainfall and temperature for 1998 and 1999 during long-rains cropping for Njoro

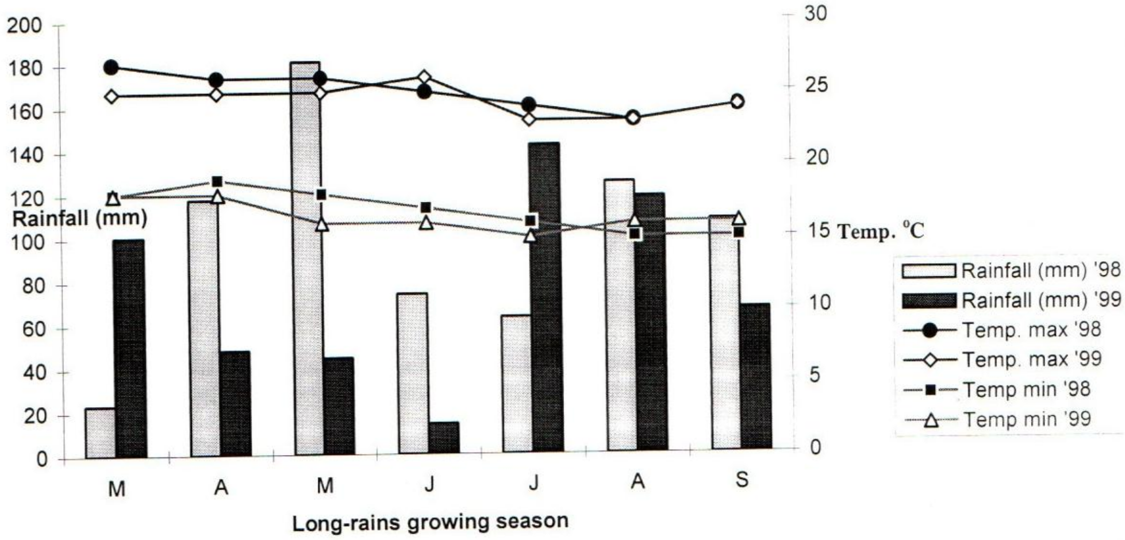

Fig A3.2; Rainfall and temperature for 1998 and 1999 during long-rains cropping season for Rongai

Appendix 4: Additional maize crop growth indices

Table A4.1; Effect of fallow management on maize biomass at V6 growth stage as expressed in dry matter weight (Mg ha^{-1})

F-Management Treatments	**Njoro DM yield (Mg ha^{-1})**		**Rongai DM yield (Mg ha^{-1})**	
	1998	**1999**	**1998**	**1999**
Chickpea	0.75^{ab}	0.49^{ab}	0.29^{b}	0.42^{a}
Field bean	0.86^{ab}	0.42^{ab}	0.24^{b}	0.42^{a}
Soybean	1.06^{ab}	0.33^{b}	0.27^{b}	0.28^{a}
Garden pea	0.93^{ab}	0.33^{b}	0.16^{b}	0.32^{a}
Dolichos lab lab	1.20^{a}	0.68^{a}	0.58^{a}	0.46^{a}
Maize	0.49^{b}	0.35^{b}	0.11^{b}	0.35^{a}
Fallow	0.57^{ab}	0.20^{b}	0.19^{b}	0.30^{a}

Means followed by the same letter in the column are not significantly different as per Duncan means separation procedure (α=0.05)

Table A4.2; Influence of preceding fallow management treatments and N fertilizer on vegetative tissue and grain N (%) in maize at Rongai during 1998 cropping season.

	Vegetative tissue N (%)				**Grain N (%)**			
	Nitrogen levels (Kg ha^{-1})				**Nitrogen levels (Kg ha^{-1})**			
Fallow management treatments	**0**	**30**	**60**	***Fallow Mgt means***	**0**	**30**	**60**	***Fallow Mgt means***
Chickpea	0.89	0.72	0.95	**0.85^{a}**	1.50	1.45	1.74	**1.56^{a}**
Field bean	0.76	0.96	0.87	**0.86^{a}**	1.74	1.66	1.68	**1.69^{a}**
Soybean	0.76	0.85	0.89	**0.83^{a}**	1.32	1.66	1.44	**1.47^{a}**
Garden pea	0.82	0.82	0.74	**0.79^{a}**	1.14	1.78	1.92	**1.61^{a}**
Dolichos lablab	0.96	0.88	1.06	**0.97^{a}**	1.65	1.64	1.79	**1.69^{a}**
Maize	0.53	0.52	0.67	**0.57^{b}**	1.63	1.51	1.66	**1.60^{a}**
Fallow	0.93	0.68	0.78	**0.80^{a}**	1.35	1.81	1.59	**1.58^{a}**
N means (N %)	**0.77^{a}**	**0.81^{a}**	**0.85^{a}**		**1.48^{b}**	**1.64^{ab}**	**1.69^{a}**	

CV (%) = 22.59 and 18.04 for vegetative tissue and gain N respectively

Fallow management means followed by the same letter in the column are not significantly different as per Duncan means separation procedure ($\propto$=0.05)
Nitrogen treatment means followed by the same letter in the row are not significantly different according to the Duncan means separation procedure ($\propto$=0.05)

Table A4.3; The effect of fallow management and inorganic-N treatments on leaf numbers at V9 stage in maize.

	Leaf count at V9 (Number/plant)							
	Njoro				**Rongai**			
	Nitrogen levels (Kg ha^{-1})				**Nitrogen levels (Kg ha^{-1})**			
Fallow management treatments	**0**	**30**	**60**	*Fallow Mgt means*	**0**	**30**	**60**	*Fallow Mgt means*
Chickpea	8.50	7.33	6.66	**7.50**^{ab}	7.11	8.33	8.66	**8.03**^{ab}
Field bean	8.67	6.67	7.83	**7.72**^{ab}	7.00	7.89	8.55	**7.81**^{ab}
Soybean	7.50	9.17	8.17	**8.28**^{a}	6.88	7.66	7.44	**7.33**^{b}
Garden pea	7.66	6.83	8.00	**7.50**^{ab}	7.11	6.88	7.66	**7.22**^{b}
Dolichos lablab	8.33	8.00	7.83	**8.05**^{a}	8.33	9.66	9.00	**9.00**^{a}
Maize	5.66	6.00	6.83	**6.16**^{c}	5.55	6.22	6.00	**5.92**^{c}
Fallow	6.50	6.50	7.00	**6.66**^{bc}	5.66	6.89	7.55	**6.70**^{bc}
N means (Number/plt)	**7.54**^{a}	**7.21**^{a}	**7.47**^{a}		**6.80**^{b}	**7.65**^{a}	**7.84**^{a}	

CV (%) =11.40 and 17.05 for leaf count at Njoro and Rongai respectively

Fallow management means followed by the same letter in the column are not significantly different as per Duncan means separation procedure ($\propto$=0.05)
Nitrogen treatment means followed by the same letter in the row are not significantly different according to the Duncan means separation procedure ($\propto$=0.05)

Table A4.4; The effect of fallow management and inorganic-N treatments on leaf numbers at R2 stage in maize.

F-Management treatments	Nitrogen levels (Kg ha^{-1}) 0	30	60	*F-Mgt Means (No. plant^{-1})*
Chickpea	10.22	10.22	11.33	**10.59^{ab}**
Field bean	10.22	10.33	11.66	**10.74^{ab}**
Soybean	10.55	10.33	11.00	**10.62^{ab}**
Garden pea	9.11	10.33	11.00	**10.14^{bc}**
Dolichos lab lab	11.88	11.22	11.44	**11.51^{a}**
Maize	9.44	9.00	9.77	**9.40^{c}**
Fallow	9.66	10.11	10.11	**9.96^{bc}**
N Means (No. plant^{-1})	**10.15^{b}**	**10.22^{ab}**	**10.90^{a}**	

CV (%) = 10.69

Table A4.5; Influence of fallow management and N fertilizer treatments on leaf area index (LAI) at R2 growth stage in maize during 1998 cropping season.

F-Management treatments	Nitrogen levels (Kg ha^{-1}) 0	30	60	*F-Mgt Means*
Chickpea	1.99	1.89	2.22	**2.03^{b}**
Field bean	1.82	1.83	1.89	**1.85^{bc}**
Soybean	1.93	1.96	1.92	**1.93^{b}**
Garden pea	1.74	1.46	1.97	**1.72^{bc}**
Dolichos lab lab	2.62	2.67	2.44	**2.58^{a}**
Maize	1.37	1.45	1.46	**1.43^{c}**
Fallow	1.70	1.88	1.93	**1.84^{bc}**
N Means	**1.88^{a}**	**1.88^{a}**	**1.98^{a}**	

CV (%) =23.98

Fallow management means followed by the same letter in the column are not significantly different as per Duncan means separation procedure ($\propto$=0.05)

Nitrogen treatment means followed by the same letter in the row are not significantly different according to the Duncan means separation procedure ($\propto$=0.05)

Table A4.6; Maize ears (cobs) as influenced by fallow management and N fertilizer treatment at Njoro and Rongai during 1999 cropping seasons.

	Maize cobs in 1999 (number plant^{-1})							
	Njoro				**Rongai**			
	Nitrogen levels (Kg ha^{-1})				**Nitrogen levels (Kg ha^{-1})**			
Fallow management treatments	**0**	**30**	**60**	***Fallow Mgt means***	**0**	**30**	**60**	***Fallow Mgt means***
Chickpea	1.00	1.33	1.00	**1.11^{a}**	1.05	1.05	1.22	**1.11^{a}**
Field bean	0.89	1.22	1.33	**1.14^{a}**	1.00	1.17	1.27	**1.14^{a}**
Soybean	1.00	1.33	1.00	**1.11^{a}**	1.00	1.05	1.05	**1.03^{a}**
Garden pea	1.16	1.00	1.33	**1.22^{a}**	1.11	0.83	1.22	**1.05^{a}**
Dolichos lablab	1.00	1.11	1.22	**1.11^{a}**	1.11	1.05	1.22	**1.13^{a}**
Maize	1.11	0.77	1.33	**1.07^{a}**	1.05	1.05	1.11	**1.07^{a}**
Fallow	1.11	1.11	1.11	**1.11^{a}**	1.11	1.11	1.00	**1.07^{a}**
N means (number plt^{-1})	**1.03^{a}**	**1.13^{a}**	**1.19^{a}**		**1.04^{b}**	**1.06^{b}**	**1.15^{a}**	

CV (%) = 21.5 and 13.64 for cobs per plant at Njoro and Rongai respectively

Fallow management means followed by the same letter in the column are not significantly different as per Duncan means separation procedure ($\propto$=0.05)
Nitrogen treatment means followed by the same letter in the row are not significantly different according to the Duncan means separation procedure ($\propto$=0.05)

Appendix 5; Weed density and species distribution

Table A5.1; Weeds species density and per cent( ) of the total population m^{-2} per treatment at V4 growth stage in maize at Njoro during 1999 cropping season.

	Short-rains season management system						
Weed species	**Chickpea**	**Field bean**	**Soybean**	**Garden pea**	**Dolichos**	**Maize**	**Fallow**
Ageratum conyzoides							0.33 (2.3)
Ammaranthus hybridus	3.33 (20.7)	1.67 (12.6)	0.33 (4.6)	1.78 (9.9)	3.22 (18.1)	4.00 (21.2)	1.78 (12.5)
Bidens pilosa		0.11 (0.8)					
Brassica napus	0.56 (3.4)			0.89 (5.0)		0.67 (3.5)	0.11 (0.8)
Commelina benghalensis							0.22 (1.6)
Conyza sp.							0.11 (0.8)
Crotolaria sp.	0.11 (0.7						
Cyperus sp.	3.44 (21.4)	0.56 (4.2)	1.89 (26.2)	3.22 (18.0)	2.22 (12.5)	0.78 (4.1)	2.44 (17.2)
Datura stramonium		2.0 (15.1)	0.33 (4.6)	0.78 (4.3)	0.78 (4.4)	1.00 (5.3)	0.78 (5.5)
Digitaria scalarum				0.11 (0.6)		0.44 (2.4)	3.56 (25)
Galinsoga parviflora	2.78 (17.2)	3.33 (25.2)	3.11 (43.1)	8.78 (49.1)	1.78 (10.0)	7.89 (41.8)	1.00 (7.00)
Nicandra physaloides			0.22 (3.1)	0.11 (0.6)			
Oxalis latifolia	5.22 (32.4)	5.44 (41.2)	0.78 (10.8)	2.22 (12.4)	8.78 (49.4)	3.67 (19.4)	1.78 (12.5)
Pennisetum clandestinum						0.11 (0.6)	0.33 (2.3)
Polygonum convulvulus						0.11 (0.6)	
Setaria pulludfusca	0.22 (1.4)	0.11 (0.8)	0.56 (7.7)		0.11 (0.6)		
Solanum nigrum	0.11 (0.7)					0.22 (1.2)	
Tagetes minuta					0.89 (5.0)		1.67 (11.7)
Verbena bonariensis							0.11 (0.8)

Table A5.2; Weeds species density and per cent ( ) of the total population m^{-2} per treatment at V4 growth stage in maize at Rongai during 1999 long-rains cropping season.

	Short-rains season management system						
Weed species	**Chickpea**	**Field bean**	**Soybean**	**Garden pea**	**Dolichos**	**Maize**	**Fallow**
Ammaranthus hybridus	0.22 (24.7)		0.11 (20.0)			0.33 (4.2)	0.56 (5.7)
Bidens pilosa	0.11 (12.3)		0.11 (20.0)				0.56 (5.7)
Chloris gayana							0.44 (4.6)
Commelina benghalensis	0.44 (49.4)	0.11 (33.7)				0.56 (7.0)	2.89 (29.9)
Cyperus sp.			0.11 (20.0)			0.11 (1.4)	1.22 (12.6)
Digitaria scalarum						0.33 (4.2)	
Galinsoga parviflora		0.22 (67.3)	0.11 (20.0)			6.56 (83.1)	2.33 (24.1)
Portulaca oleraceae			0.11 (20.0)				
Tagetes minuta							1.67 (17.2)

Table A5.3; Weeds species density and per cent ( ) of the total population m^{-2} per treatment at 6th leaf stage in wheat at Njoro during 1999 cropping season.

	Short-rains season management system						
Weed species	**Chickpea**	**Field bean**	**Soybean**	**Garden pea**	**Dolichos**	**Wheat**	**Fallow**
Ammaranthus hybridus	0.67 (16.7)	0.67 (7.9)	3.67 (41.8)	1.44 (27.1)	0.67 (22.2)	2.22 (33.9)	3.33 (29.5)
Brassica napus	1.33 (33.3)	0.67 (7.9)	0.33 (3.8)	0.56 (10.4)	0.11 (3.7)	0.56 (8.5)	1.78 (15.7)
Cyperus sp.	1.22 (30.6)	3.11 (36.9)	4.22 (48.1)	0.89 (16.7)	0.56 (18.5)	2.78 (42.3)	1.78 (15.7)
Datura stramonium				0.11 (2.1)	0.33 (11.1)		0.22 (2.0)
Digitaria scalarum							0.33 (2.9)
Galinsoga parviflora	0.11 (2.8)	2.33 (27.6)	0.22 (2.5)	1.56 (29.2)			
Oxalis latifolia	0.22 (5.6)						0.56 (4.9)
Pennisetum clandestinum							1 (8.8)
Polygonum convulvulus				0.11 (2.1)	7.4 (9.1)		
Setaria pulludfusca	0.33 (8.3)	0.11 (1.3)	0.33 (3.8)	0.44 (8.3)	0.78 (25.9)	1 (15.2)	0.22 (2.0)
Solanum nigrum				0.22 (4.2)	0.22 (7.4)		1.22 (10.8)
Tagetes minuta	0.11 (2.8)	0.33 (3.9)			0.11 (3.7)		0.89 (7.9)

Table A5.4; Weeds species density and per cent ( ) of the total population m^{-2} per treatment 6th leaf stage in wheat at Rongai during 1999 cropping season.

	Short-rains season management system						
Weed species	**Chickpea**	**Field bean**	**Soybean**	**Garden pea**	**Dolichos**	**Wheat**	**Fallow**
Ammaranthus hybridus		0.11 (16.6)		0.22 (67.3)			0.11 (0.9)
Bidens pilosa							0.56 (4.4)
Brassica napus							0.33 (2.6)
Chloris gayana							0.11 (0.9)
Commelina benghalensis							0.11 (0.9)
Cyperus sp.			1.78 (99.9)				1.11 (8.7)
Galinsoga parviflora							8.44 (66.5)
Oxygonum sinuatum							0.44 (3.5)
Portulaca oleraceae		0.56 (82.9)		0.11 (33.7)			
Tagetes minuta							1.44 (11.4)