SMALL-HOLDER UTILITY-BASED PHYTO-IONOMIC DIVERSITY MAPPING AT LAKE BASIN SITES IN THE INTEREST OF NUTRACEUTICAL-IMPLIED SECURITY

Hezekiah Opiyo Orwa

B.Sc. Agriculture (University of Nairobi)

A Thesis Submitted in Partial Fulfilment of the Requirements for the Award of the Degree of Master of Science in Agricultural Resource Management

Department of Plant Science and Crop Protection,

Faculty of Agriculture,

University of Nairobi

June 2011

DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

Signature ....Date. 04/07/2011 ....

Hezekiah Opiyo Orwa

APPROVAL:

This thesis has been submitted for examination with our approval as University supervisors

Signature ....Date. 04/07/2011 ....

Prof. Levi S. M. Akundabweni

Department of Plant Science and Crop Protection

University of Nairobi

Signature ....Date. 06/07/2011 ....

Dr. George N. Chemining'wa

Department of Plant Science and Crop Protection

University of Nairobi

DEDICATION

This work is dedicated to my wife Beatrice and children Lynn and Rodney for their encouragement and sacrifice during the difficult period of study.

ACKNOWLEDGEMENTS

My profound gratitude goes to my supervisor Prof. L. S. M. Akundabweni for his assistance and advice throughout the project work. Despite his busy schedule, he was available for consultation any time, be it physically, through emails or through telephone communication. The facilities he provided at his lab office hastened my work. I must thank him for helping to arrange for financial support of this work through VicRes' Lake Victoria Basin programme. I sincerely appreciate VicRes for the sponsorship without which I would have been faced with serious financial difficulties. I am also indebted to Dr. George Chemining'wa for taking his time to read my work and for his valuable advice from project conception, proposal development to report writing.

I acknowledge the help and support I received from the Institute of Nuclear Science, University of Nairobi laboratory staff where I analyzed plant samples using XRF spectroscopy technology. The Director of the institute, Dr. David Maina gave me unlimited access to laboratory facilities for use even during weekends. Messrs Simion Bartilol and Joseph Njogu were always available to assist with the operation of the XRF equipment and also provided other further technical guidance and advice.

The field visits to Emuhaya and Vihiga to study the farms and collect samples as well as the subsequent sample preparation for analysis would have been unmanageable without the efforts of research assistants Bernadette Mwaizi, Evelyn Wairimu, Sussy Munialo and Japheth Ambuka. The cooperation given by the farmers and the Ministry of Agriculture staff on the ground, Messrs Walter Musoga, Festus Asilutwa and Henry Keya made this bit even easier.

Above all I adore the almighty God according to whose grace and plan this dream has been realized and ask Him to bless and reward all those who supported and prayed for me.

TABLE OF CONTENTS

List of Figures **Page**

List of Tables **Page**

List of Appendices **Page**

Table of meanings of acronyms

ACRONYM	STANDS FOR
ACP-EU	Africa Caribbean and Pacific-European Union
AIVs	African Indigenous Vegetables
CAPRi	Critical Assessment of Prediction of Interactions
CTA	The Technical Centre for Agricultural and Rural Cooperation
CVD	Cardio Vascular Diseases
EDXRF	Energy Dispersive X-ray Fluorescence spectroscopy
NHIVs	Nutrahealth implied Ionomic Variations/variants
FAO	Food and Agricultural Organization of the United Nations
H-NHIVs	High Nutrahealth implied Ionomic Variations/variants
IPGRI	International Plant Genetic Resources Institute (currently Bioversity International)
KARI	Kenya Agricultural Research Institute
LBKF	Left side of the house back kitchen garden on flat ground
LBKS	Left side of the house back kitchen garden on sloping ground
LBKV	Left side of the house back kitchen garden on valley land
LFF	Left side of the house far farm on flat ground
LFS	Left side of the house far farm on sloping ground
LFV	Left side of the house far farm on valley land
L-NHIVs	Low Nutrahealth implied Ionomic Variations/variants
M-NHIVs	Mid Nutrahealth implied Ionomic Variations/variants
MCA	Multi channel analyzer
NGOs	None Governmental Organizations
NHBF	Near house farm border on flat ground
NHBS	Near house farm border on sloping ground

NHBV	Near house farm border on valley land
PPM	Parts per million
RBKF	Right side of house back kitchen garden on flat ground
RBKS	Right side of house back kitchen garden on sloping ground
RBKV	Right side of house back kitchen garden on valley land
RFF	Right side of house far farm on flat ground
RFS	Right side of house far farm on sloping ground
RFV	Right side of house far farm on valley land
SADCC	Southern Africa Development Cooperation Community
S*H*A*R*P	Soil*Human*Animal*Rates*Plants interaction
SMART	Scripting, Mark- mining, Aggregating, Targeting, Rating and Targeting
TAGEs	Traditional Agro Ecologies
TAGEs	Traditional Agro-Ecologies
TLVs	Traditional Leafy Vegetables
UNEP	United Nations Environment Programme
UNESCO	United Nations Education, Scientific and Cultural Organization
UNESCO	United Nations Educational, Scientific and Cultural Organization
XRF	X-ray fluorescence spectroscopy
SHUB-Ionomic	Small holder utility based-Ionomic
SDU	SHUB-Ionomic Diversity Unit
WELSPAN	Water, Ecology, Land, Soil, Plants, Animal, and Nutrient fluxes
CUD	Cardio-Vascular Diseases
MMN	Mineral Micro-Nutrients
SCWW	Status, Content, Which and Where

Operational definitions of terms

Term	Meaning
Recommended nutrient intake	Daily intake which meets the nutrient requirements of almost all (97.5%) apparently healthy individuals of an age and sex specific population.
Allocationing	Land use decisions for placement of specific agricultural bio resources and/or farm structures at particular positions on the farm taking into consideration the position of the house (e.g. Viewsheds).
Locationing	A principle of land adaptation to bio resource. A bio-resource practice that entails deliberate positioning of a cropping decision point (e.g. Walkshed). Topography (location) influenced cropping decisions.
Viewshed	Site reference relating to the direction and distance from the house described as near house border (NHB), left back kitchen garden (LBK), right back kitchen garden (RBK), left far farm (LF) and right far farm (RF).
Walkshed	Topographic reference of a site indicating whether it is a flat land on the upper terrain (F)-, sloping land (S), or Valley land (V).
Decision points	Sites or venues or points or accommodations of adaptations e.g. of crop to topographies, or walksheds as an interface between the allocationing and the locationing phases.
Foodshed mapping design.	The mapping design representing bio-resource micronutrient placement based on the topography (walkshed) and the distance and direction from the house (viewshed). It depicts the relative importance of the various layers with regard to bio-resource micronutrient diversity, density and availability.
Ionomes	Accessions described in terms of their mineral nutrient and trace element composition. An ionome is generally defined as the mineral nutrient and trace element unit varying in composition as represented in the inorganic component of the cellular and organismal system.
SHUB-Ionomic Diversity Unit (SDU)	Smallholding, farm or a homestead-farm habitat described in terms of utility based micronutrient dietary diversity.
SHUB-Ionomic diversity	Small holder utility based-Ionomic diversity. It is a concept that looks at the diversity on the small hold farms in terms of the different species available that are used as food and their micronutrient and health value.

Nutraceutical value	The nutritional and health giving value of food items. The word "nutraceutical" is coined from "nutrition" and "pharmaceutical".
Type I nutrients	This classification is based on how the body responds to a nutrient deficiency. Type I response gives rise to biochemical abnormalities that are transient (i.e. deficiencies with clinical signs). Two categories of type I nutrients are the minerals Fe, Cu, Mn, I, Ca, F, the phytochemicals: vitamins, and others e.g. Thiamine, Folate, Ascorbic acid, Vitamin D and Vitamin K. Type I nutrients are storable and when they are depleted the body becomes ill.
Type II nutrients	Type II responses may result into more or less permanent abnormalities without specific diagnostic chemical changes. They involve elements like K, Na, Mg, Zn, P, and the gaseous ones are O_2 and H_2O, and important ones like Protein (Nitrogen and Carbon skeletons of amino acids). There are no body stores for type II nutrients other than normal tissue and their deficiency evokes preservation of plasma and tissue levels, at the expense of growth, repair and immunity.
'Locavores' & 'Locavorous'	People and the associated behaviour who are perceived as best placed to eat within a local foodshed. The interest of locavores preferring to eat within their TAGEs can readily be aroused by the premise for this thesis that they can live longer on more nutraceutically rich foods that require less energy to produce, indigenous food crops that support the local (county) economy while allowing producers-cum-consumers as the locavores enjoying a more personal connection with their land (TAGE unit/farm), soil - to – plant mineral micronutrient flows and the indigenous agro-diversity linked to land use decisions.

General Abstract

Continued land sub-division in the smallholder Traditional Agro-Ecologies (TAGEs) together with the changing circumstances of climatic variability, reduced land productivity, external influences, commercialization tendencies, and growing markets for specific products, have led to increased challenges regarding land use decisions. A reduction in the agro-phyto-diversity in smallholder farms which has resulted into reduced dietary diversity in TAGEs may be indirectly attributed to these changes. Dietary diversity as an aspect of agro-phyto-diversity derives its qualitative and quantitative food and nutrition importance from the interactions between the plants' genetic potentials and the environment. Among other parameters, food and nutrition quality are particularly important in terms of the micronutrient density/quality which addresses a hidden hunger. In this regard, the smallholder farms where the foods are produced may be looked at as the Small-Holder Utility-Based Ionomic Diversity Units or SHUB-Ionomic Diversity Units (SDUs).

This study thus endeavoured to assess the state of SHUB-Ionomic diversity as a general aim by investigating its linkage to micro-foodshed conditions and women-operated land use practices at Lake Victoria Basin (LVB) Kenyan Eco-region Sub-basin site. The specific objectives of the study were: (1) To determine the state of agro-phyto-diversity in smallholder traditional agro-ecologies of Esibuye and Vihiga; (2) To determine the agro-phyto-diversity and soil mineral micronutrient contents in the micro-SDUs or smallholdings, linked to 'View-walk' landscape morphology of the SDU and; (3) To map out the 'view-walk' agro-phyto-diversity and nutrahealth-implied ionomic variation (NHIV).

The study design was hierarchical in which 'view-walk' sections were nested within SDUs within TAGEs within Lake Victoria-Kenyan sub-basin within Lake Victoria Basin. The TAGEs were

Vihiga Upper hill (the VU) ecology in Vihiga district and the Esibuye Foothill Lower (the EFL) ecology in Emuhaya district. Fifteen SDUs within each of the TAGEs were selected and sectioned into 'view-walk sections as determined by an interaction between the topography referenced 'walkshed' and the house position referenced 'viewshed'. There were five 'Viewshed' positions described as: Near-house, Left Mid-farm, Right Mid-farm, Left Far-farm and Right Far-farm) juxtaposed with 3 'Walksheds' namely: Upland, Sloped and Valley land use types. An individual SDU (farm unit) thus had 15 view-walk sections to it.

Data were acquired by carrying out agro-phyto-diversity inventory and micronutrients content analysis of plant samples (n=95 of 2008 short rains accessions and n = 35 of 2009 accessions) and soil samples (n= 92) using X-Ray Fluorescence spectroscopy. Agro-Phyto-diversity-Directed (APD) questionnaires were also administered to the smallholder women operators to determine the trends in agro-phyto-diversity 'allocationing' and 'locationing' as well as related information regarding popularization and use of species.

Some 157 and 151 accessions were encountered in the VU and EFL ecologies, respectively, implying that the agro-phyto-diversity distribution under the two TAGEs was similar, probably due to the constant gene flow between the two neighbouring ecologies. Variation in the number of fruit, cereal & pulses and vegetable culti-groups were significantly affected by the 'view-walk' allocationing and locationing decisions at both 5% and 1% levels of confidence. The agro-phyto-diversity distribution ratios between near-house : mid-farm : far-farm were 15:55:30 and 41:42:17 in Esibuye and Vihiga, respectively. These data give a sense of less land pressure in Esibuye relative to Vihiga as may be suggested by the more intensive use of the near house sections of SDUs in Vihiga.

Results for mineral micronutrient agro-phyto-diversity contents linked to 'Viewshed' and 'Walkshed' decision factors revealed that only 18% of the 130 plant accessions were of medium to high NHIV grades with score-card grades ranging from 5 to 8 and 82% of all accessions were of low NHIV grades with score-card grades from 1 to 4. Three amaranth accessions (S09F30VNU P74, S09F38ENU P70, and S09F40ENU P84) and one local kale accession (S09F33ENU P87) were singled out for being the top graded micronutrient dense in two consecutive seasons even though they were not among the popularized species. Mapping of NHIV grades on the SDU sections suggested that plants growing near the house and possibly accessed more readily may be those that are generally of the low to medium mineral micronutrient density grades and this may be due to the fact that the near house position in smallholder agro ecologies is dominated by vegetable species that have less residues resulting into more nutrient mining. The staple food crops such as maize, bananas, and beans were the most popularized and also the most conserved and 'improved' by adoption of new varieties in the study area. The disappearing crops were identified as comprised of cassava, finger millet, carrots, bulrush millet, sorghum and sweet potatoes. The market was found to be the leading source for new planting materials and thus very important in movement of germplasm between ecologies.

Conclusions made are that agro-phyto-diversity in Vihiga and Esibuye SDUs is fairly limited and is facing a further risk of constriction; in effect, hidden hunger could, therefore, be a risk in TAGEs. Popularization of the more micronutrient dense ionomes, while sustaining agro-phyto-diversity and avoiding un-popularization of indigenous species, is recommended as a sustainable strategy of advancing the utility based management of bio-resources in TAGEs.

CHAPTER ONE

Introduction

1.1 Background information

1.1.1 The study sites

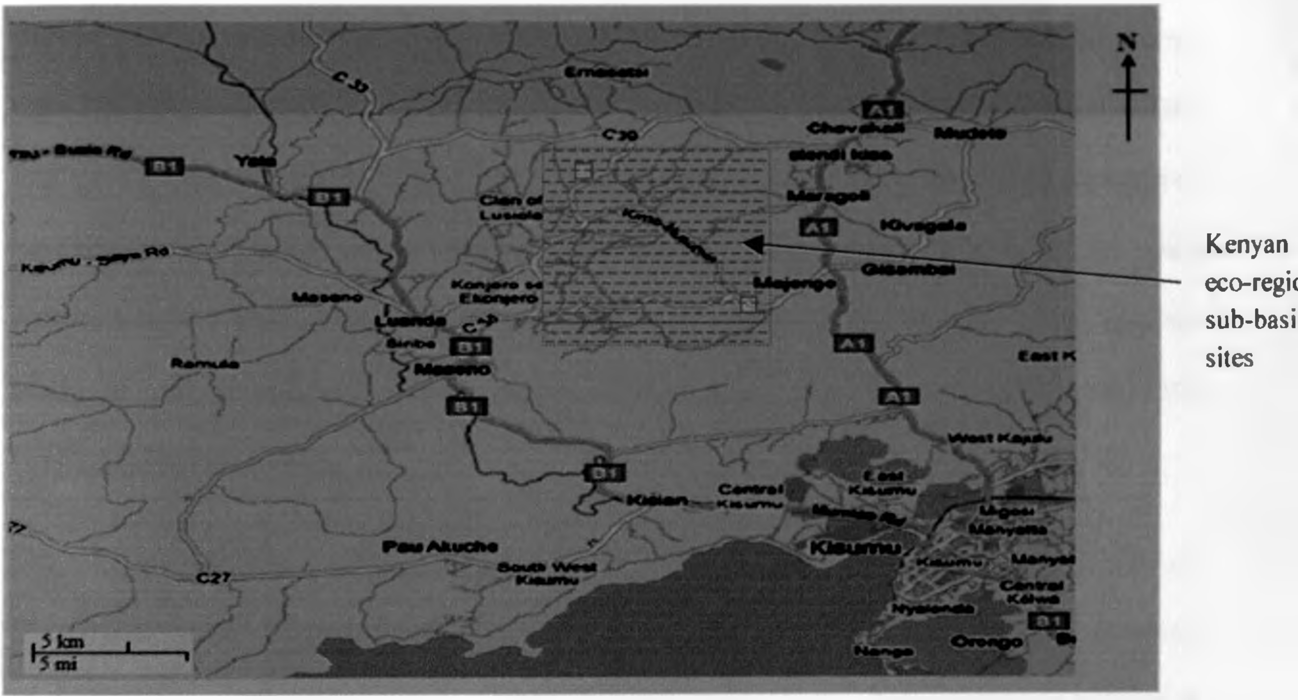


Figure 1.1: Map showing the location of the two study sites (Esibuye & Vihiga) and surrounding areas.

Source: www.googlemaps.com

The study was conducted at two agro-ecological sites (Vihiga and Emuhaya district) in the Lake Victoria Basin. Emuhaya district borders Khwisero district to the North West, Kisumu West to the South, Vihiga district to the East, Sabatia to the North East, Gem district to the West and Ikolomani district to the North. The district has two major Agro Ecological Zones namely Upper Midland Zone 1 (UM1) - Coffee-Tea zone covering 95% of district and Lower Midland Zone 1

(LM1) - Sugar cane zone covering 5% of district (MoA, 2009). Vihiga District on the other hand borders Hamisi district to the East, South Kakamega district to the north, Emuhaya district to the west and Kisumu West District to the south. The altitudes of both Emuhaya and Vihiga range between 1,300 m and 2000 m above sea level, (MoA, 2008). The hill and the foot-hill ecosystems were the Vihiga and Esibuye sites in Vihiga and Emuhaya Districts, respectively. Fifteen SHUB-lonomic Diversity Units (SDUs) (farm units) per site were systematically selected on the basis of membership to particular women groups as identified by their leaders. SDUs in Esibuye were scattered around Esibuye market with geographical coordinates 0.081367, 34.638691 whereas those in Vihiga radiated around Majengo centre at coordinates 0.038795, 34.71302 (www.googlemaps.com)

The soils were generally poor in fertility due to their age, leaching and continuous nutrient mining. The project site in Vihiga had shallow soils with some steep slopes and sandy loam soil structure, whereas the site in Emuhaya has clay loam soils with gentle slopes. The soil type in Esibuye is dystric Acrisol which is deep, well drained, and slightly acidic to alkaline (MoA, 2009).

The long term average rainfall amount ranges from 1500 mm to 1700 mm in the upper midland zone and from 1300 mm to 1500 mm in the lower midland zones (Schmidt and Jaetzold, 1982). Both sites experience bimodal rainfall pattern from February to late May and late August to late November for the long and short rains, respectively. During the year 2009 the amount of rainfall realized in the area were recorded at the District Agricultural offices as 812.4mm in Emuhaya and 1824.1mm in Vihiga (see Appendices 1.2a-1.2c). Average minimum temperature is higher than 20.5°C.

The concept of SHUB-Ionomic Diversity Unit in a foodshed context has been presented both as a tool for understanding the flow of food in the food system and as a framework for envisioning alternative food systems (Christian et al. 2008). The Food and Agricultural Organization (F.A.O) of the United Nations has proposed the reduction of the geographical distance between producers of food and its consumers as a measure to help mitigate ecological, economic and social concerns associated with transportation of food from production points to consumers (FAO, 2008). In this regard, the smallholder TAGEs may be viewed as an ideal food system since it demands minimal transportation in a case of consumption that remains within a primary destination. This system also referred to as the SDU – short for SHUB-Ionomic Diversity Unit is comprised of the small scale farm and the local market place. In a TAGE, the smallholder farm unit generally is allocated to a residential as well as food provision SDU and is a continually constricting space that is subject to inheritance-induced land fragmentation with the ever rising population. Faced with the changing circumstances of reduced resource capacity, climatic variability, reduced land productivity, external influences, commercialization tendencies, growing markets for specific products, and increased environmental awareness, the operators in TAGEs have had to change their management from the traditional and well-balanced at the expense of the system's agro-phyto-diversity as they have introduced exotic varieties thus relegating some of the otherwise high quantity and quality packaged indigenous species. In retrospect, the arising questions include the following: (1) To what extent is the TAGE quantitative and qualitative phyto-dietary diversity sufficiently studied to contribute to the technical recommendations for the sustainable management of the highly utilized TAGE system? And, (2) Who are the various stakeholders to engage in sustainable strategies at the SHUB-Ionomic Diversity Unit level?

At the household level, interventions in the SDU that address agro-phyto-diversity conservation and use are linked not only to bio-resource management practices but are also affected by the management of the View-walk aspects of the SDU unit. Thus the smallholder farm unit can be looked at as being comprised of a Viewshed perceived as the viewable indication of residential dwelling in relation to cropping positional prescriptions. A Walkshed, on the other hand, is the topography-influenced choice of land use along the terrain (i.e. upland, sloped land and the plain/valley) 'walks' (Akundabweni-Personal communication), and in principle, it has a lot to do with natural adaptations. Viewshed positional partitions (Near-house farm position, mid-farm and far farm) most likely represent a deliberate phyto-diversity scoping (allocations) and the kind of horticultural/agronomic practices employed whereas the walkshed, to a large extent, likely influences the plant-soil-water relations, adaptation, bio-resource protection/conservation and land use patterns (FAO, 1995). Thus on-farm Viewshed by Walkshed (View-walk) 'allocationing' and/or 'locationing' decisions are of interest in understanding the existing agro-phyto-diversity positions and its nutraceutical implications. 'Allocationing 'principle applied in this study is that of the placement of the cropping decisions that are house-referenced. 'Locationing' on the other hand are the topographically-influenced cropping decisions. Both decision types are likely to be important factors that determine the State of agro-phyto-biodiversity Content (C), in terms of Which (W) it is and Where (W) it is (i.e. S-C-W-W)? In other words View-walkshed is an independent factor while S-C-W-W represents the dependent variables. The premise of this study is that the View-walkshed by S-C-W-W cause-effect relationship is a mappable dimension which can provide invaluable guidelines in the formulation of policies for managing the TAGEs in women operated smallholder SDUs of the Lake Victoria Basin.

1.2 Problem statement

Women operators on SDUs are faced with many challenges that have come with reduction in the sizes of their land holdings. In a bid to adapt to the changed circumstances, uninformed decisions have been made that have affected the qualitative and quantitative diversity of foods produced and/or accessed for use by the households. The nutraceutical implied consequences of these decisions can be understood from an S-C-W-W analysis.

1.2.1 The State of agro-phyto-diversity

The capacity of SDUs to provide diversified quantitative and qualitative phyto-content is steadily declining due to genetic erosion and loss of soil fertility. Genetic erosion and soil fertility loss can be attributed to the adoption of the kind of 'allocationing' (deliberate positioning of a cropping decision point) and/or the 'locationing' (topography influenced cropping decisions) technologies, introduction of exotic crops/varieties, reduction of the biodiversity spectrum (especially with regard to indigenous vegetables, fruits and cereals), commercialization of agriculture, and changes in feeding habits as well as environmental degradation. Genetic erosion has resulted into limited variation of the household diet and its associated hidden hunger which is manifested in malnourished children and adults as increased health problems (Hughes, 2008).

1.2.2 The agro-phyto Quantitative and Qualitative Content problem in relation to View-shed and Walk-shed factors

The mineral micronutrient issues which determine the plant concentration/density are directly influenced by what comes from the soil. So when the nutrient fluxes favour the loss of soil nutrients through surface run-off, leaching and /or massive soil erosion, or excessive nutrient mining; the resulting plant concentration may in effect be negatively affected. In upper-hill ecology, the soil mining plus the physical losses of the soil sourced micronutrients may be a problem affecting both the qualitative or quantitative mineral micronutrient densities likely to be encountered in crops grown in the SDUs (Grusak, 2002).

1.2.3 The 'Which' problem of the agro-phyto-diversity in relation to View-walkshed

The three most important culti-groups being cereals, vegetables, and fruits, overemphasis on staple food cereals such as maize may very easily overrun the inclusion of other agro-phyto-diversity species in the 'allocationing' and the 'locationing' decisions. The problem in the study area is that maize is the most predominant cereal at the expense of other cereals such as millet and sorghum (Ndufa et al. 2005). This has resulted in reduction in phyto-diversity and hence increased risk of mineral micronutrient insecurity.

1.2.4 The 'Where' problem of agro-phyto-diversity in relation to View-walkshed

Moreover as to what extent a crop is protected from destruction by wildlife or rodents and other pests and/or even theft may influence the spectrum of an otherwise natural distribution within an SDU. The walkshed 'locationing' decisions depend much on the natural terrain of the land which may also affect the soil-water-plant interactions that determine the bioavailability of the soil mineral micronutrients to the plants and ultimately to the human consumers (Msuya et al. 2008). Food preference and utilization rates of crops influence the positioning of phyto-diversity in relation to the view shed reference to the house position. This 'allocationing' decision factor in turn also affects the utilization rate by determining the ease by which the crop can be accessed from the kitchen. Thus the quantitative and qualitative nutraceutical implied value that is derived from the SDU may be limited by the management decisions that women operators make with respect to the view-walk decision factors.

1.3 Justification of the study

A primary reason for many vitamin and mineral deficiencies in the developing world is lack of green leafy vegetables in the diet. Studies have shown that availability and accessibility influence the type and qualities of food eaten in both urban and rural areas (Oguntona et al. 1987). Concentration of micronutrients in plant accessions varies from location to location depending on the prevailing environmental conditions. Therefore, decline in agro-phyto-diversity in smallholder SDUs and changes in view-walkshed 'allocationing' and 'locationing' decisions may be affecting the nutraceutical-implied security of households in traditional agro-ecologies. It is therefore necessary to analyze the status and trends of agro-phyto-diversity in smallholder traditional agro ecologies, and the SDU content to determine which foods are accessible and where they are found in the SDU as well as their nutraceutical-implied value. This will provide an information basis for recommending appropriate intervention decisions that must be made towards reducing hidden hunger among subsistence households in TAGEs. The study is based on the on-farm bio-resource mapping conceptual model represented schematically in Appendix 1.1.

1.4 Objectives and hypothesis

1.4.1 Overall objective

To map the Small-holder utility-based bio-resource micronutrient diversity at Lake Basin sites in the interest of nutraceutical-implied security.

1.4.2 Specific objectives

1. To determine the state of agro-phyto-diversity in smallholder traditional agro-ecologies of Esibuye and Vihiga.

2. To determine the agro-phyto-diversity and soil mineral micronutrient contents in the SHUB-Ionomic Diversity Units linked to 'Viewshed' and 'Walkshed' decision factors (i.e. practices, choices and management).

3. To map out the positions of diverse plant accessions on the SHUB-Ionomic Diversity Unit and their respective implied nutra-health ionomic variants (NHIVs).

1.4.3 Hypothesis

The underlying hypothesis in this study is that agro-phyto-dietary diversity and quality in SDUs and destinations have not suffered reduction under the current farm land-use topographic and residence referenced crop positioning changes.

1.5 Study design

The study was based on the SHUB-Ionomic Diversity Units TAGEs model. The model developed by Prof. Akundabweni of the University of Nairobi (Unpublished material) looks at SHUB-Ionomic Diversity Units (SDUs) in traditional agro-ecologies (TAGEs) as potentially consisting of 15 View-cum-walk landscape sections (Figures 1.2 and 1.3).

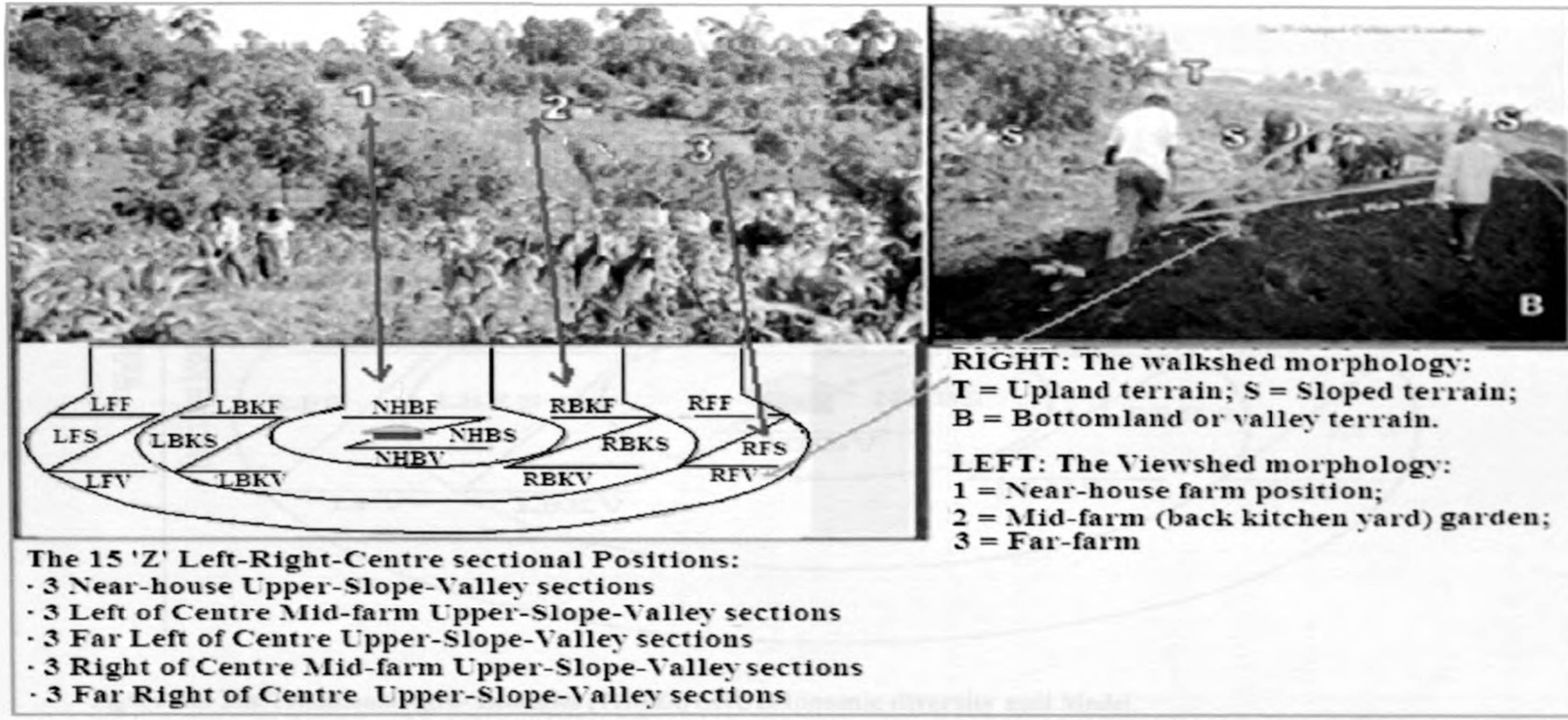


Figure 1.2: A typical SHUB-Ionomic Diversity Unit (SDU) in Traditional Agro- Ecologies (TAGEs)

Legend: NHBF=Near house border on flat ground, NHBS=Near house border on sloping ground, NHBV=Near house border on valley land, LBKF=Left back kitchen garden on flat ground, LBKS=Left back kitchen garden on sloping ground, LBKV=Left back kitchen garden on valley land, RBKF=Right back kitchen garden on flat ground, RBKS=Right back kitchen garden on sloping ground, RBKV=Right back kitchen garden on valley land, LFF=Left far farm on flat ground, LFS=Left far farm on sloping ground, LFV=Left far farm on valley land, RFF=Right far farm on flat ground, RFS=Right far farm on sloping ground, RFV=Right far farm on valley land.

Source: Akundabweni (unpublished)

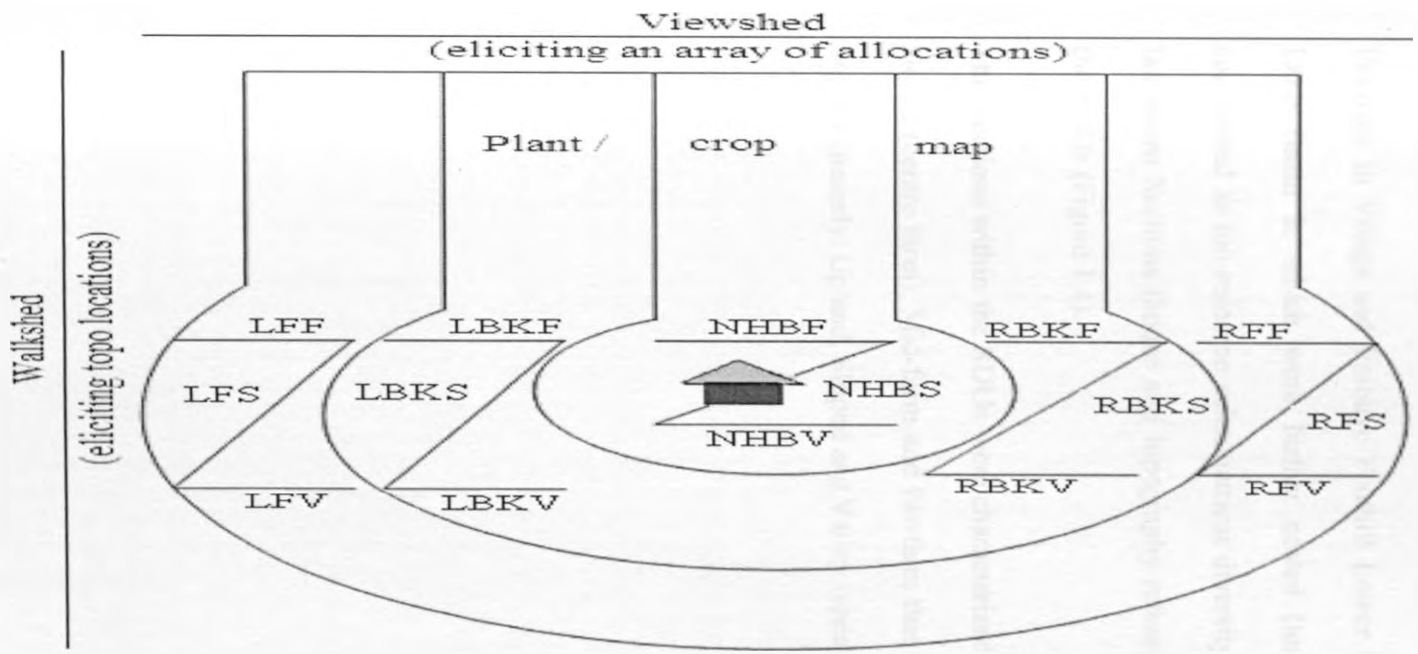


Figure 1.3: The Traditional Agro- Ecologies (TAGEs) SHUB-Ionomic diversity unit Model.

Legend: NHBF=Near house border on flat ground, NHBS=Near house border on sloping ground, NHBV=Near house border on valley land, LBKF=Left back kitchen garden on flat ground, LBKS=Left back kitchen garden on sloping ground, LBKV=Left back kitchen garden on valley land, RBKF=Right back kitchen garden on flat ground, RBKS=Right back kitchen garden on sloping ground, RBKV=Right back kitchen garden on valley land, LFF=Left far farm on flat ground, LFS=Left far farm on sloping ground, LFV=Left far farm on valley land, RFF=Right far farm on flat ground, RFS=Right far farm on sloping ground, RFV=Right far farm on valley land, 'Z'= denotes three walksheds; the 'bulbs' or onion layers are the respective viewsheds.

Source: Model developed by Akundabweni (Unpublished)

'Sections-in-SDUs-in-TAGEs-in-Lake Basin' design was hierarchical in respect of the LVB-Kenya and LVB-Uganda with the eco-region project area forming the primary level. This study concentrated in LVB-Kenya. Traditional Agro-ecologies (TAGEs), namely; Vihiga Upper hill Ecology in Vihiga and Esibuye Foothill Lower Ecology in Emuhaya were nested within the Lake Basin in which were further nested (tertiary level) the smallholding units (farms) considered as bio-resource micronutrient diversity units. At the 5^{th} level, the View-cum-Walk landscape Sections (house and topography referenced respectively) were in turn nested within the SDUs (Figure 1.4).

The Sections within the SDUs were characterized as having a 3-View toponym, namely; Near-House (centre farm), Mid-farm and Far-farm that were juxtaposed with the land use 'walkshed' aspects (namely: Upland, Sloped and Valley types) for reconnaissance.

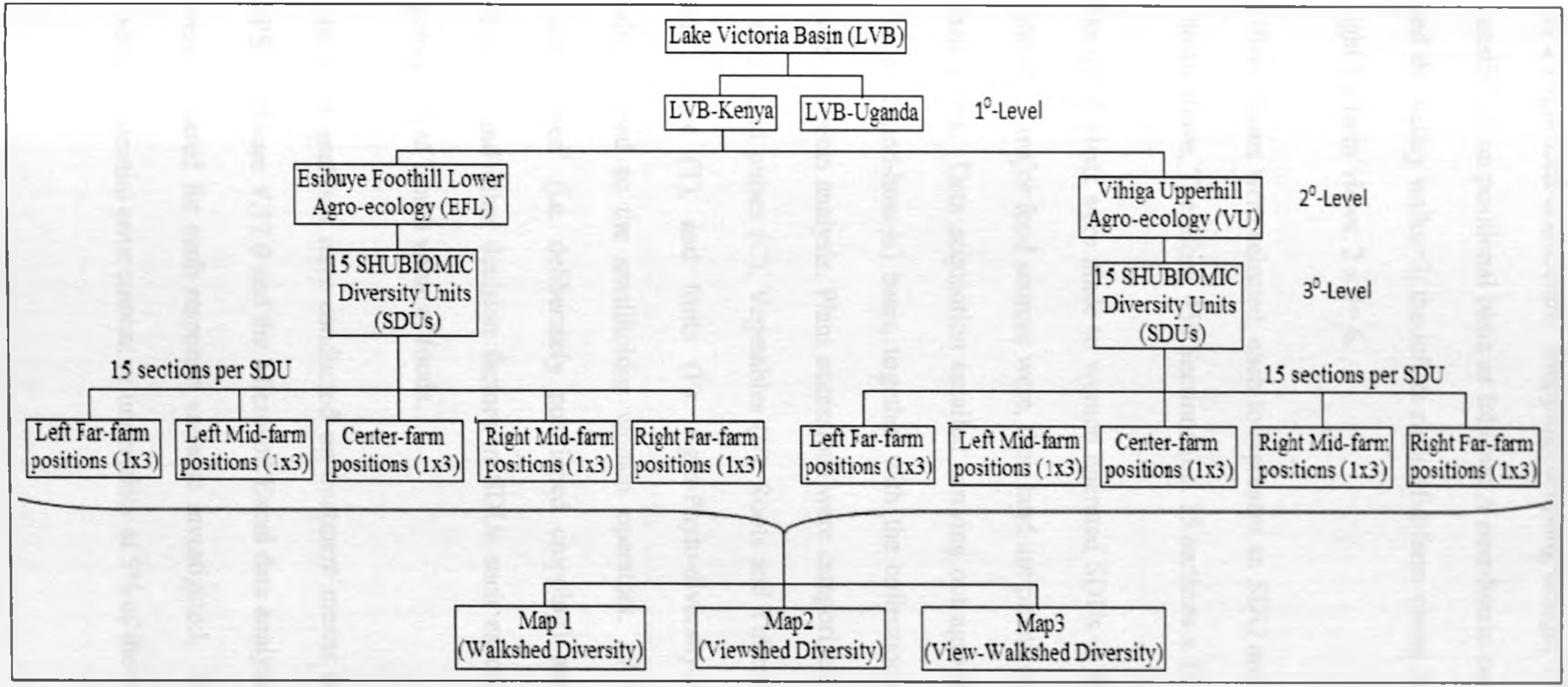


Figure 1.4: Schematic representation of the hierarchical study design.

Note: Sections nested within SDUs; SDUs within Ecologies; and Ecologies within Country sub basins

As a Right-Left-and-Centre' Mapping/Sampling design, 15 sampling sections on each SDU were constituted on positional basis as follows: A near-house centre View: 1 by the upland walk, sloped and the valley walks=3; the left & right Mid-farm views from the farm house: 2 x 3=6; the left & right far farm views: 2 x 3= 6.

Fifteen farms were selected, each to represent an SDU and the latter in effect sectioned into 15 as shown above. Therefore, 450 Sections (i.e. 15 sections x 15 SDUs x 2 TAGEs) were sampled.

Designed visits were made to women operated SDUs in Esibuye and Vihiga TAGEs to establish what their major food sources were, their land use practices and the diversity of foods produced on their farms. Data acquisition entailed carrying out agro-phyto-diversity inventory on a free-call (i.e. as found-how-is) basis, together with the collection of plant and soil samples for mineral micronutrients analysis. Plant accessions were categorized into six arable or culti-groups namely: Cereals and pulses (C), Vegetables (V), Roots and Tubers (R), Snacks and minor crops (S), Tea and coffee (T), and fruits (F). Agro-Phyto-diversity-Directed (APD) Questionnaires were administered to the smallholder women operators. APD data were analyzed to determine 'allocationed' (i.e. deliberately positioned cropping) and topographically 'locationed' phyto-diversity and other decision factors in SDUs such as crop popularization ranking and farmers perception of health value of foods.

Statistical analyses were conducted on treatment means using the t-test and F-test procedure of SPSS software V.12.0 and the Microsoft Excel data analysis functions. Analysis of variance tables were prepared for each response variable investigated. Error bars were used with bar charts to indicate potential error amount or uncertainty at 5% of the value of each data point.

CHAPTER TWO

2.0 Literature Review

2.1 On farm phyto-diversity and indigenous foodshed utilization

A number of studies have been made on land use changes and the trend of utilization of traditional crops as affected by various factors. Studies in the Southern Africa Development Cooperation Community region have shown that there is a decline in the utilization of traditional vegetables (Attere, 1990). Vorster et al. (2008), and Abukutsa-Onyango (2008), have noted the loss of on farm phyto-diversity in smallholder agro-ecologies in Kenya. Mitra and Pathak (2008) reported that the availability of fruits and vegetables on the farm is declining while at the same time impoverished farmers cannot afford to buy them from the market. A study by the National Museums of Kenya revealed that people especially the youths were despising their indigenous foods in favour of exotic or introduced foods (UNESCO, 2008).

These changes have had implications on soil nutrient fluxes (Akundabweni, unpublished), phyto-nutrients' diversity choice(s) and their placement positions on TAGEs with respect to land-use topography decisions. As reliance upon staple food cropping increased, dietary diversity diminished. Mnzava (1995) argued that, as food choice and hence dietary diversity diminished the probability that all essential nutrients obtainable from underutilized/neglected/or orphaned indigenous plants also diminished thereby increasing vulnerability to malnutrition and hidden hunger especially among the poor, the sick, pregnant women and children.

It has been noted that a primary reason for many vitamin and mineral deficiencies in the developing world is lack of green leafy vegetables in the diet (Wanjiru, 2004). Further, a study in Borno, Nigeria showed that availability influenced the type and qualities of food eaten in both urban and rural areas (Oguntona et al. 1987). It has been shown that phyto-diversity in TAGEs is reducing (Vorster et al. 2008 Abukutsa-onyango, 2008, and Mitra and Pathak 2008) and that the nutritional values of plant foods vary with the environmental conditions at their sources (Brady and Well, 2002; Barber, 1995; Msuya ,., 2008). An understanding of the characteristics of the primary sources of foods for communities (i.e. SDUs) is therefore important in determining whether they are able to access adequate nutritional benefits especially with regards to mineral micronutrients.

2.2 The concept of 'foodshed' analysis and its application to rural households' nutraceutical' implied security

Analogous to a watershed, the concept of a foodshed has been presented both as a tool for understanding the flow of food in the food system and as a framework for envisioning alternative food systems. Walter Hedden described a 'foodshed' in 1929 as the 'dikes and dams' guiding the flow of food from producers to consumers (Christian et al. 2008). Foodshed has been defined by Christian et al. (2008), as the geographic area from which a population derives its food supply. This definition borrows from the understanding of the watershed concept but unlike the physical barriers that define watersheds, foodsheds are delineated more often by socio-economic than physical factors.

Foodsheds exist at different scales as initially described by Homenway (2006) and reproduced by Christian et.al (2008). A personal foodshed may include the gardens and markets within an individual's walking or bussing distance while an urban foodshed might cover much of a state or bioregion. A smallholder/primary/individual foodshed may be considered as "a Small Holder Utility-based Ionomic Diversity Unit (SHUB-Ionomic Diversity Unit)" that is diversified by both the walk- and the viewshed sub-aspects and may be sufficient to provide food for a given household, and neighbourhood (Akundabweni, 2008). A foodshed's boundaries are permeable and allow some specialty and out-of season foods to come from outside through trade with other foodsheds.

'Foodshed analysis' therefore refers to the study of actual or potential sources of food for a population, particularly those factors influencing the movement of food from its origin as agricultural commodities on a farm to its destination as food wherever it is consumed. Analyses of foodsheds can provide useful and unique insights on everything between where food is produced and where food is consumed including the diversity of the food, the land it grows on, the route it 'travels', the market it goes to, the processing it undergoes and the nutraceutical implied value it provides to the locavores (the locals) and other likely consumer destinations that are beyond (see the operational definitions on page xvi).

"Travelling" as is used in this context is twofold: travelling of mineral nutrients from the soil to the people's bodies via plant foods and travelling of the produce from the farm to a consuming locavore destination which may either be primary and/or secondary foodshed e.g. a local market place or a supermarket. The interest in the region-based consumption is paramount here.

The capacity of the individual SDU to provide foods with good nutraceutical implied value is a function of its management in terms of the diversity of plant species present, their 'allocationing' on specific view-walkshed (viewshed and walkshed interaction) sections, the fertility of the land and how it is conserved for sustainability.

2.3 Soil spatial variability in the field and nutrient availability to plants with SHUB-Ionomic diversity building potential under human influence

Soil properties are variable at all levels from a few meters to many kilometres. This geographic variation of soil is largely dependent upon the five factors which are responsible for soil formation (i.e. climate, parent material, organisms, topography and time) (Barber, 1995). Most small scale soil variations involve changes in topography, so an awareness of even subtle changes in slope is critical to understanding how soil properties change across a landscape. Soil pH is a major determinant of nutrient bioavailability (Brady and Well, 2002). But plant nutrition involves biological, physical, and chemical processes and interactions among many different components of the soil and the environment. These include minerals, air, water and organic matter (Barber, 1995) and the plants' inherent characteristics (ionomic potential). Man influences this complex interaction through management interventions that may involve slope management, soil and water conservation, addition of soil amendments and plant nutrients, agro-biodiversity control, and species 'allocationing' and 'locationing' on the farm. These interventions come as a result of land management decisions made by the operators. Decision making at the farm level is influenced by a complex of interacting factors.

2.4 Interactions between factors influencing decision making for primary SHUB-Ionomic exploitation opportunities at the farm household level

Management decisions that SDU operators have to make are influenced by a complex interaction of diverse factors. The interactions have in part been analyzed by FAO (1995) using the farm household as the primary unit of analysis of farm-level decision making (Figure 2.1). Each household has a unique set of socioeconomic and biophysical conditions; both internal and external which govern its agricultural investment and marketing decisions as well as production and conservation decisions.

The investment and marketing decisions concern:

(a) Choice of agricultural enterprises and their corresponding diversity (Perennial crops, Annual crops, Livestock/fish, and Post-harvest processing). With accurate and relevant information, plant accessions or variants with good nutrahealth implied ionomic grades may be preferred at this stage. Further investment and marketing decisions that are often made at the farm household level may be summarised in terms of the five A_s of production and marketing decisions (Akundabweni. Personal communication)

2.4.1 The five A_s of production and marketing decisions

(a) Acquisition of inputs (credit and supplies). This is the activity that is responsible for movement of germplasm between ecologies and affects the agro-phyto-diversity in SDUs.

(b) Allocationing of: land (by enterprise and by responsibility); capital (for production and for consumption); labour (family labour, hired labour, and off-farm employment). Allocation of land is often influenced by the view-walkshed sectioning of the SDU, crop popularization, and conservation and protection requirements.

(c) Assimilating the appropriate production and husbandry technologies and practices in order to attain the desired production and conservation goals.

(d) Assembling of produce through appropriate harvesting and handling, grading, processing, packaging, and storing procedures and

(e) Abandoning by identifying market channels and offloading to them (i.e. marketing)

Production and conservation decisions on the other hand are about management of the production process and how production can be sustained from year to year by minimizing damage to the available resource base. They include decisions on the administration of the production processes by adopting, adapting, altering, applying, assimilating or matching husbandry or cultural practices and resource potentials in order to optimize the quantity and quality of products and conserve the resources.

In making these decisions, operators consider many factors (both on-farm factors and off-farm factors) simultaneously. Farmers do this intuitively and they almost always have good reasons for their decisions (FAO, 1995).

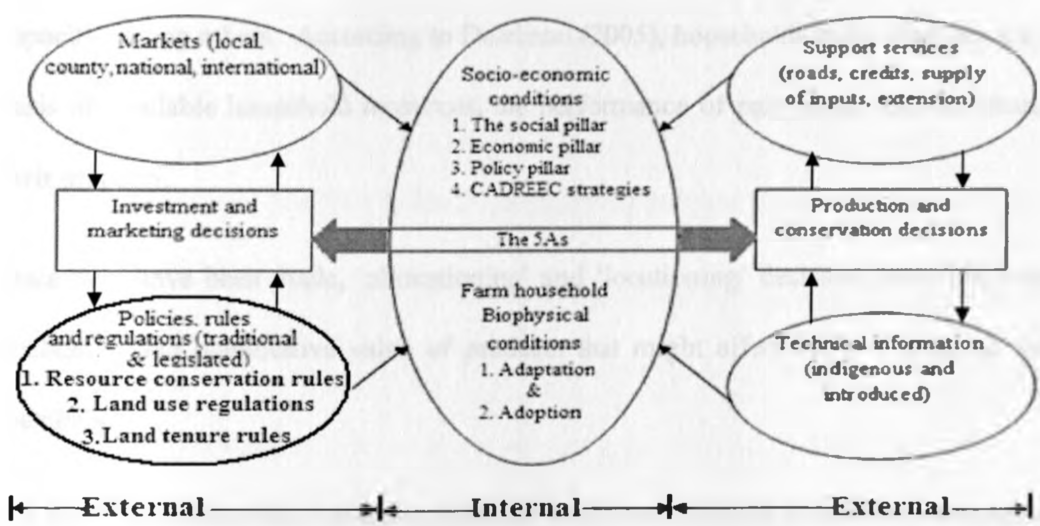


Figure 2.1: Interaction between all Factors Influencing Household Decision Making

Legend: CADREEC = Capacity Development for Research, Education, Extension and Communication; 5As = Acquisitioning, Allocationing, Assimilating, Assembling, and Abandoning (i.e. disposal or downloading to the consumers).

Source: Adapted from FAO, 1995

There are a number of tools available for matching species diversity in the SDU with biophysical factors such as: Slope, Soil (i.e. depth, stability, fertility, and texture), Altitude, Aspect (i.e. North/South orientation, wind direction), and Moisture (i.e. amount and distribution of rainfall, and/or irrigation), and Biological factors (pests, diseases). Biophysical factors are, for the most part, beyond the control of the farm family, but they have a direct influence on the agro-phyto-diversity in TAGEs and its implied nutraceutical value. The socioeconomic factors that affect farm decisions are also varied and not all of them are within the control of a single smallholder farm operator. They include: policies, rules, and regulations which govern management of agricultural lands and are enforced by the state and community. Others are external support services (e.g. roads, farmers associations, extension services), and household demographics and its resource capacity among others. According to Deadman (2005), households make land use decisions on the basis of available household resources, the performance of past crops, and the characteristics of their property.

Once they have been made, 'allocationing' and 'locationing' decisions have implications on the qualitative and quantitative value of products that might affect the wellbeing of the household members.

2.5 Women as custodians of agro-phyto-diversity and linkage to land use management and their rights in respect to household nutrition

Often regarded as the custodians of the agro-phyto-diversity, an African woman tends to produce and prepare food for the household as well as exchange knowledge about natural resource management. Women are thus, the main operators of smallholder farms or home gardens across the agro-phyto-diversity to – farm to - food. Despite this role, many women gain access to land to operate on rather than to be deed titled as are men (CAPRi, 2006). This affects their decisions and actions on the farm and may hinder them from discretional land use options and diversifying food enterprises and maintaining soil fertility that contributes its nutrients to diversity in micronutrient density. The women farm operators are further constrained by small and reducing land sizes of holdings. Bashaasha et al. (2006), correlated the well being of any household with the size of the land it owns and suggested that *ceteris paribus*, the odds that the wellbeing of a particular household will be above any given level will be 7.08 times higher for households owning 5 and above acres of land than for households owning less than 5 acres of land. As the land size reduces; the fertility of the land also tends to decline fast due to continuous cultivation without addition of external nutrients, there is a tendency by farmers to concentrate on a few staple food crops and some commercialized vegetables. Commercial varieties have a tendency for monoculture farming. These affect tastes and preferences and cause a decrease in dietary diversity especially among the rural households.

2.6 Home-gardening land use linked to conserving species' diversity and mitigating hidden hunger

Home-gardening can affect household nutritional status through direct consumption of produce. More than 95% of the diet in Nepal is supplied through plant species and home gardens are the major sources, supplying 60% of the household's total fruit and vegetable consumption (Gautam et al. 2009). Home-gardens have the potential to provide a significant amount of different foods which can improve micronutrient density status and on the overall human nutrition. Indirectly, the benefits of home-gardens can come through savings due to reduced purchases and increased income from sale of produce. Linked to land use, functional benefits of home-gardens have been listed by Ninez (1987) as: Production of considerable food on land areas in home-gardens which tend to be too small for field agriculture; The smallholding home gardens generally require low inputs and do not degrade the environment; they are of mixed species supplying nutritional benefits lacking in field agricultural production; Gardens provide a readily accessible nutrient supply; provide food during times of agricultural disruption; they are adaptable to respond to particular needs and resources of households and act as laboratories for experimentation with new plants and cultivation techniques; they fulfil other household needs such as supply of fodder, and petty cash from sale of produce; and gardens have a convenient and secure labour source – women, children, and the elderly. Studies in Nepal revealed that home gardens are rich in species diversity, ranging from 11 – 87 species of vegetables, fruits, fodder, ornamental plants, spices, and species with medicinal and cultural use values. Further a number of uncultivated, neglected and underutilized species with economical, nutritional, social, cultural, religious and medicinal values are conserved in home-gardens (Gautam et al. 2009).

Home gardens are not fully developed in structure and function to maximize their potential in meeting the demands of households. Dietary diversity has been shown to have a direct positive relationship with the number of species grown in the home gardens. Promotion of diversity of species in home gardens as one of the strategies to improve dietary diversity of resource poor families in rural areas is, therefore, warranted.

However with increasing population and pressure on land, families are increasingly depending entirely on these small pieces of land around the home because that is all they have. It has therefore, become necessary to institute measures that will ensure that the households derive adequate nutraceutical security (i.e. the nutrient and health giving value of food) from the home garden. Farmers in TAGEs need to be made aware of the importance of ensuring sustained phyto-diversity on the farm and the nutraceutical value inherent in diverse indigenous crops as well as the implications of the management decisions that they make.

2.7 Malnutrition problem in the developing world of the 'locavores' of a local foodshed

Approximately 840 million people in the world suffer from chronic hunger and more than two billion suffer from micronutrient deficiencies or "hidden hunger" (Christian et al. 2008). Malnutrition is implicated in one-third to one-half of all child deaths each year (Kristof, 2009). Thiam et al. (2006), has listed chronic diseases related to diet and nutrition as diabetes, hypertension, obesity, cardiovascular disease (CVD), cancer, osteoporosis and dental disease. They observed that in many parts of sub Saharan Africa, notably among urban dwellers there has been a marked increase in the prevalence of these diseases and that obesity and diabetes are not only affecting large proportions of the population but also have began to appear earlier in life. This has been accompanied with concomitant decline in infectious and maternal child health related diseases. The World Bank calculates that increased malnutrition in 2008 may have caused an additional 44 million children in the developing world to suffer permanent physical or mental impairment (The World Bank group 2008). The hardships have recently been exacerbated by elevated food prices and declining remittances from workers abroad due to the global financial crunch. A panel of prominent economists produced the "Copenhagen consensus" on which forms of aid are most cost-effective, and it ranked micronutrient supplements as No. 1, malaria prevention as No. 12, and sanitation as No. 20 (Kristof, 2009). This confirms that micronutrient deficiency is a major problem affecting vulnerable communities and especially the resource poor women headed households. This is because they have been neglected by researchers as scientists continue to concentrate on research subjects that only benefit the more endowed farmers.

2.7.1: Mitigating malnutrition in local foodshed

"Malnutrition is not a glamorous field, and so it's routinely neglected by donor governments, poor countries and, journalists" Observed Kristof, (2009). Intermittent interventions by governments and NGOs often target single nutrients such as vitamin A supplementation campaigns and involve high logistical costs. But the sustainability of such programs cannot be guaranteed. Besides, some children are often missed out. It should also be understood that nutrients work in concert to give the best results. Locavorous production and consumption of diversified and nutritious foods can probably be the most effective and sustainable strategy to address the problem of hidden hunger in smallholder rural households.

2.7.2 Traditional African Foods and their role in mitigating hidden hunger: Prospects for locavorous consumption

Africa has an enormous reservoir in the diversity of African plants and ways of using them for food and other purposes. A database containing detailed information on more than 850 species has been developed by the National Museums of Kenya under the Indigenous Food Plants Programme (www.unesco.org/shs/most). Taken as a category, traditional vegetables are extremely important for nutrition and farm income throughout Africa. They often supply most of the daily requirements for vitamins A, B complex and C of poor rural people (Mepba et al. 2007). Unfortunately, poverty, famine, and malnutrition are still common in rural areas. This is partly because in rural poor areas vegetables and fruits are taken as supplementary foods not as the main course and most households have limited knowledge on the importance of dietary diversity for nutrition.

The diversity of African plants has already started to erode because of neglect, insufficient knowledge and inadequate support to institutions and communities that conserve biodiversity.

Many of these species ranging from annual herbs to trees are poorly known; many are used only locally; They are often being cultivated in small patches in home gardens by women or found growing as weeds in marginal areas within farms or wild in forest areas. A study by the National Museums of Kenya revealed that people especially the younger generation were despising their traditional foods in favour of exotic foods; Much local knowledge regarding the nutritional value and cultivation of local edible plants was being lost; Most people no longer knew, for example, when and where to collect seeds; A number of important species, or varieties of species, were on their way to extinction; and having never been written down, the indigenous knowledge of the elderly was slipping away day-by-day (www.unesco.org/shs/most). This trend is to the detriment of local people's health and income.

The conservation of the genetic resources of African traditional vegetables and of the wealth of indigenous knowledge about genetic variation, cultural practices and processing that is associated with them was advanced as an extremely topical and urgent issue by the CTA/IPGRI/KARI/UNEP seminar held in October 1992 at UNEP under the title "Safeguarding the genetic basis of Africa's traditional crops" (Mnzava 1995). The seminar recommended that more attention should be paid by the plant genetic resources conservation community to hitherto relatively neglected species, in particular indigenous vegetables and other so-called 'minor' crops and that more research was needed on the role played by home and kitchen gardens as repositories of biodiversity and therefore on the role of women as curators and managers of genetic resources. But more recent literature indicates that little has been done. Abukutsa-Onyango (2008) has noted that the role of African indigenous vegetables (AIVs) in poverty alleviation and food and nutrition security in Kenya has not been fully exploited. The author noted that AIVs have been generally neglected and are facing extinction, unless urgent measures are taken. Vorster et al. (2008), observed that the importance of traditional leafy vegetables (TLVs) in the food security strategies is being limited due to loss of biodiversity and the associated indigenous knowledge, which they attribute to changing climatic conditions and human preferences. Kimiywe (2009) details some indigenous vegetable recipes and their energy and micronutrient contents but their level of availability to households for consumption needs to be established.

2.8 X-ray Fluorescence Spectroscopy: A window for rousing interest to nutrraceutical implied security

X-ray fluorescence spectroscopy (XRF) is a method of elemental analysis that assesses the presence and concentration of various elements by measurement of secondary X-radiation from the sample that has been excited by an X-ray source. The method is rapid, does not destroy the sample and with automatic instruments is suitable for routine operation. When a primary x-ray excitation source from an x-ray tube or a radioactive source strikes a sample, the x-ray can either be absorbed by the atom or scattered through the material. During this process, if the primary x-ray had sufficient energy, electrons are ejected from the inner shells, creating vacancies. As the atom returns to its stable condition, electrons from the outer shells are transferred to the inner shells and in the process give off a characteristic x-ray whose energy is the difference between the two binding energies of the corresponding shells. Because each element has a unique set of energy levels, each element produces x-rays at a unique set of energies, allowing one to non-destructively measure the elemental composition of a sample (Wanjiru, 2004).

CHAPTER THREE

On-farm Indigenous Crop-diversity as conditioned by the Soil, Human, Animal, Rates and Plant (S*H*A*R*P) interactions that pave way for SHUB-Ionomic density characterization.

3.0 Abstract

The nutraceutical value derived from plant foods is influenced by complex interacting factors in the growing environment. In managed ecologies, the interactions between the plant and the natural environmental factors are often shaped by humans through environmental modifications that are aimed at increasing the quantitative and the qualitative value of plant produce. These modifications affect the Soil, Human, Animal, Plant and Rates (S*H*A*R*P) interactions that impact on the mineral micronutrient content of food plants and hence the nutrahealth implied ionomic variants (NHIV) in the farms here referred to as SHUB-Ionomic Diversity Units (SDUs).

The mineral micronutrient concentrations in soil and in the edible plant portions were analyzed with the objective of determining the agro-phyto-diversity and soil mineral micronutrient contents in the SDUs linked to 'Viewshed' and Walkshed' decision factors (i.e. practices, choices and decision management).

Three amaranth accessions in particular (S09F30VNU P74, S09F38ENU P70 and S09F40ENU P84) and one local kale accession (S09F33ENU P87) were found to be NHIV-superior. It was further found that most of the plant accessions produced for food in the TAGEs were of low NHIV grades, and that apparently, the allocationing decisions had indirect dietary nutraceutical implications on the people who live in the TAGEs and rely on the smallholder SDUs for their

food. It is, therefore, necessary to target the high NHIV grade accessions for promotional activities to increase their visibility and volume.

3.1 Introduction

The on-farm bio-resource diversity in traditional agro-ecologies is a complex of factorial diversity due to the following factors: Soil properties, Human activities / or management, Animal influence, Rates of nutrient fluxes and other related climatic factors, and Plant characteristics. The Soil*Human*Animal*Rates*Plant (S*H*A*R*P) interactions influence the extent of nutraceutical agro-phyto-diversity conservation and use. Figure 3.1 below illustrates the complex interactions between the S*H*A*R*P factors in SDUs that affect mineral micronutrient availability to plants, animals and man. Management interventions by humans through such as addition of nutrients and soil amendments, water management and plant diversity 'allocationing' and 'locationing' are aimed at optimizing the availability of nutrients to plants (1a); The rates of The agro-phyto-diversity (or Ionomic variants) in an SDU (1b) extract and transform the nutrients making them available for utilization by animals and man (1c and 1d) in quantities and qualities that are specific to the various ionomes given the interaction effects of the management interventions, the environmental conditions and the inherent capacities of the specific ionomes to mobilize mineral ions. Man can intervene by increasing agro-phyto-diversity and including the variants that have high nutrahealth implied ionomic grades.

Mineral micronutrient transformation processes take place in the soil (2a), and the products are linked to the utility purpose on the surface via plants, the efficiency of which is accession specific. The rate of exchange of ions between the clay / humus colloids and the soil solution (2b and 2b') depends on the soil properties and determine the availability of minerals for uptake by plants. The net product of all the mineral transformations that take place in the soil is what exists in soil solution as chealates (2c) that can either be taken up by plants or lost through leaching (2f').

The plant and animal residues (2e) that get into the soil form organic matter (2f) that is transformed through the action of soil organisms into chealates that go into soil solution and are either taken up by plants or lost through erosion.

The use aspect can be promoted among others by attaching a nutraceutical implied value to foods produced under smallholdings. The nutraceutical implied value of a food item refers to the apparent dietary and health benefits that consumers derive by consuming it (Akundabweni et al. 2010).

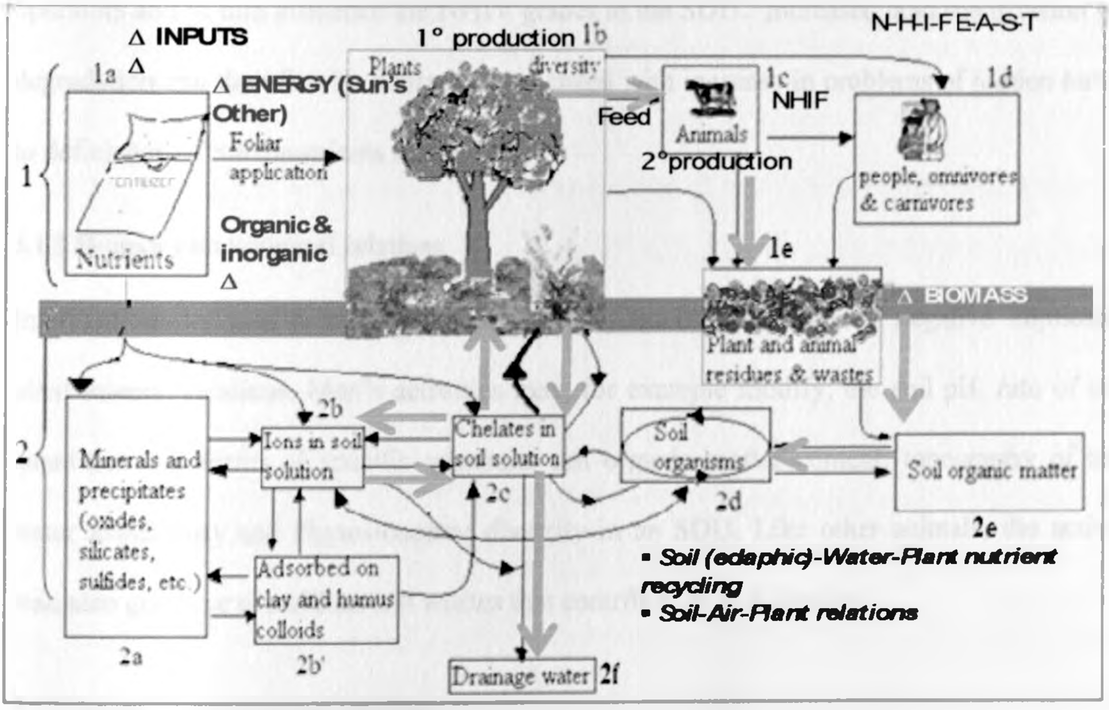


Figure 3.1: Soil-Human-Animal-Rates-Plant interaction pathways with SHUB-Ionomic diversity building potential in SDUs

3.1.1 Soil-Plant Mineral micronutrient relations in SHUB-Ionomic Diversity Units (SDUs)

Plants obtain mineral nutrients through root uptake from the soil solution (Bierman and Rosen, 1999). Soil properties that affect nutrient availability and uptake by plants are variable at all levels from a few meters to many kilometres depending upon the five factors which are responsible for soil formation (i.e. climate, parent material, organisms, topography and time) (Barber, 1995). Brady and Well (2002) explained how localized variations in soil air, water, minerals, organic matter contents, pH, and salinity influence nutrient availability to plants. Most small scale soil variations involve changes in land topography. The size and slope of the land available to a household may affect the agro-phyto-diversity 'allocationing' decisions made by the farm operators and in turn influence the NHIV grades in the SDU. Increased land sub division and land degradation can therefore be indirectly associated with increase in problems of hidden hunger due to deficiency of micronutrients in the diet.

3.1.2 Human-plant-mineral relations

Interventions by man in managed ecologies may have positive and/or negative implications on plant mineral relations. Man's activities may, for example modify; the soil pH, rate of soil loss, quantities and forms of specific minerals, soil organic matter content, topography of the land, water availability and Phyto-Ionomic diversity in an SDU. Like other animals, the activities of man also give rise to residues and wastes that contribute to soil fertility.

3.1.3 Animal-plant-mineral relations

Plant residues and manure from animals fed forage, grain, and other plant-derived foods are returned to the soil. This organic matter pool of carbon compounds becomes food for bacteria, fungi, and other decomposers. As organic matter is broken down to simpler compounds, plant nutrients are released in available forms for root uptake and the cycle begins again (Bierman and Rosen, 1999). A study of the mineral concentrations in soil–plant–animal continuum in Mizoram state in India showed significant correlation between fodder and cattle for Ca, Mg, Na, Cu, Co, Mn, Fe, and Zn except P and K (Kumaresan et al. 2009).

3.1.4 Rates of Nutrient fluxes and related factors

Nutrient fluxes in soil have been shown to vary between neighbouring watersheds in patterns that have no direct relation to the size of the watersheds but are related to the precipitation regime (Michael et al. 2001). This implies that the slope of the land also influences the export coefficient of nutrients as it affects water flow. Equally important are the rate of nutrient addition to the soil, and the rate of removal of plant residues. The rates of mobilization and accumulation of mineral nutrients by plants has been shown to be determined by genetic traits of specific ionomes (Baxter et al. 2009). A positive balance of the rates of exportation and importation of nutrients through nutrient cycling processes may enrich the agro-phyto-diversity in an SDU and in effect the desired NHIV. These rates are often modified by human through management practices.

3.1.5 Plant-mineral micronutrient relations

Concentration of minerals in a plant's tissues is influenced by its genetic characteristics. Baxter et al. (2009), showed that *Arabidopsis* mutants, characterized by increased root suberin, had decreased accumulation of Ca, Mn, and Zn and increased accumulation of Na, S, K, As, Se, and Mo in the shoot. Rus et al. (2006), identified genes from wild populations of *Arabidopsis* that are involved in regulating how plants acquire and accumulate Na^+ from the soil. This shows that genetic variations among plants have implications on the diversity and concentration of mineral micronutrients in their edible tissues. Accessions can, therefore, be described in terms of their mineral nutrient and trace element composition as 'ionomes'. The ionome is defined as the mineral nutrient and trace element composition of an organism and represents the inorganic component of cellular and organismal systems (Salt et al. 2008).

3.1.6 The Concept of foodshed analysis and its application to rural households' nutraceutical implied security

Foodshed has been defined as the geographic area from where a population derives its food supply (Christian et al. 2008). Foodshed analysis refers to the study of actual or potential sources of food for a population, particularly those factors influencing the movement of food from its origin as agricultural commodities on a farm to its destination as food wherever it is consumed. Analysis of foodsheds can provide useful and unique insights on the diversity of the food, the land it grows on, the route it 'travels', the market it goes to, the processing it undergoes and the nutra-health implied value it provides. 'Travelling' in this context is twofold: travelling of mineral nutrients from the soil to the people's bodies via plant foods and travelling of the produce from the farm to a consuming destination which may be a secondary foodshed e.g. a local market place or a supermarket.

The foodshed concept is analogous to that of watershed, but unlike the physical barriers that define watersheds, foodsheds are delineated by socio-economic factors. Its boundaries are permeable and allow some specialty and out-of season foods to come from outside through trade with other foodsheds.

A smallholder/primary/individual foodshed may be considered as an SDU that is diversified by both the walk-& the viewshed sub-aspects and may be sufficient to provide nutra-health foods for a given household, and neighbourhood (Akundabweni, 2008). The capacity of the individual SDU to continually provide nutra-health foods is a function of its management in terms of the diversity of plant species present, their 'allocationing' on specific View-walkshed sections, the fertility of the land and how it is conserved for sustainability.

3.1.7 Justification of the study

The localized variation in the S*H*A*R*P factors that affect phyto-ionomic diversity in SDUs may be responsible for variations in the mineral micronutrient densities in plant tissues and hence the Nutra-Health implied Ionomic Variants (NHIV) grades. Translating agro-phyto-diversity in terms of NHIV grades can serve to enhance use and conservation of the diminishing popularity of indigenous plants.

3.1.8 Objective and Hypothesis

The objective of this study was to determine the mineral micronutrient concentrations in the agro-phyto-diversity and soil at different View-walk sections of Esibuye and Vihiga SDUs. The underlying hypothesis was that the View-walkshed 'allocationing' and 'locationing' decision factors in TAGEs have got no nutraceutical value implications in SDUs.

3.2 Materials and Methods

3.2.1 Sampling and initial preparation of samples before analysis

Samples of edible portions of plant tissues were collected from each of the 15 View-walk referenced sections and samples of top soil (0-15cm) from the three topography referenced 'walksheds' (top, sloped and valley) sections of the SDUs. The samples were air dried then oven dried at 50°C for 30 minutes. Dry samples were then ground and passed through a 0.2 mm sieve. Half a gram of the powder was compressed in a pellet die to a pressure of between 10 and 15 kg, using a manual hydraulic press into round pellets of 2.5 cm diameter which were taken through X-ray fluorescence spectroscopy (XRF) analysis. Soil samples were analyzed using Mid-infrared radiation (MIR) spectroscopy analysis as described by Shepherd and Marcus (2007) then calibrated with XRF data for a randomly selected sub-sample.

3.2.2 Determination of mineral content of plant and soil samples using X-ray Fluorescence (XRF) Spectroscopy

The Energy Dispersive X-ray Fluorescence (EDXRF) spectroscopy system at the University of Nairobi's Institute of Nuclear Science and Technology laboratory was used to analyze the mineral micronutrient content of plant and soil samples. The system consists of an X-ray spectrometer with Cd-109 radioisotope source, a Canberra Si (Li) detector, an ORTEC spectroscopy shaping amplifier (model 571), an ORTEC high voltage supply bias (model 459), an ORTEC liquid nitrogen monitor, a Canberra multichannel analyzer or a spectral data processing unit: MCA (100) linked to a personal computer (Figure 3.2). The computer is used for data storage and quantitative analysis.

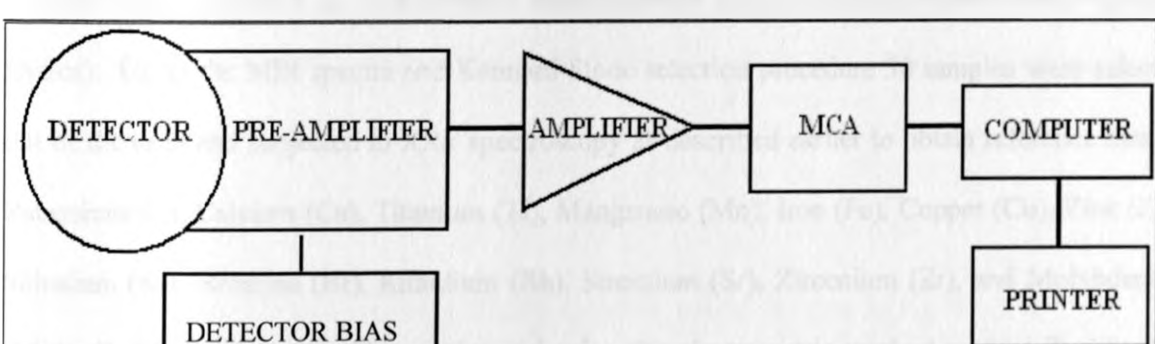


Figure 3.2: Electronic set-up for energy dispersive X-ray fluorescence spectroscopy (EDXRF) analysis equipment at the Institute of Nuclear Science and Technology - UoN.

Each pellet was weighed, placed on sample holder and irradiated for 2000 seconds and the results saved as a unique multichannel analyzer (MCA) file. A molybdenum target was then placed on top of each pellet and further irradiated for 10 seconds. The latter readings were used to calculate the absorption corrections during quantitative analysis. The mineral concentration data for each sample was generated using Quantitative X-ray Analysis System (QXAS/AXIL) – a DOS based software package for quantitative X-ray fluorescence analysis, in grams per gram and then converted to parts per million.

3.2.3 Determination of mineral content of soil samples using Mid-Infrared Spectroscopy

The Mid-Infrared Spectroscopy (MIR) equipment at the World Agro forestry centre laboratory in Nairobi was used to analyze soil samples for their mineral content and pH. Infra-red (IR) spectroscopy works on the principle that materials are composed of molecules consisting of atoms linked together by bonds (e.g. C-H, O-H, and N-H), which are constantly vibrating in two modes: stretching and bending. The resulting absorbance of light at different frequencies produces a characteristic spectrum of a substance.

A double sampling approach was used (Keith and Markus, 2007), whereby a library of 92 soil samples were subjected to Mid-Infrared measurements using Tensor-27 spectrometer (Bruker Optics). Using the MIR spectra and Kennard-Stone selection procedure 30 samples were selected out of the total and subjected to XRF spectroscopy as described earlier to obtain reference data of Potassium (K), Calcium (Ca), Titanium (Ti), Manganese (Mn), Iron (Fe), Copper (Cu), Zinc (Zn), Selenium (Se), Bromine (Br), Rubidium (Rb), Strontium (Sr), Zirconium (Zr), and Molybdenum (Mo). Reference data for pH was obtained using the electrometric method as described in (BS 1377-9:1990).

Partial least square (PLS) regression method was then used to calibrate the MIR spectra to the reference data. The spectra were processed using first derivative to remove spectra noise and baseline correction with the reference data set. A suitable transformation was evaluated to normalize the data where the natural log gave the best performance.

3.3 Data analysis

Average mineral element concentrations in each accession were computed in parts per million (ppm). The ppm data for six variation picking mineral elements comprising potassium (K), calcium (Ca), iron (Fe), strontium (Sr), manganese (Mn), and zinc (Zn) were used to derive NHIV grades for each accession using NHIV method developed by Akundabweni et al. (2008) (see Appendix 2.1). The accessions were hence described by their NHIV grades which formed the basis of further statistical analyses.

3.3.1 Statistical methods

Statistical analyses were conducted on treatment means using the SPSS for windows 12.0 software. Graphs capturing trends and relationships were drawn using MS Excel and SPSS function tools. Analyses of variance were performed on the data to determine the significance of nutrient density grade placement with respect to the viewshed and walkshed decision factors (Appendices 3.2a, and 3.2b).

3.4: Results

3.4.1: Nutrahealth-implied Ionomic Variant grading and allocationing on SDUs

Eighty four percent of all the accessions analyzed were of low NHIV grade (or reserve corridor), whereas the medium and high NHIV grade accessions comprised only 15% and 1%, respectively (Figure 3.3). Hidden hunger could therefore be a risk in Esibuye and Vihiga SDUs. Amaranth and pumpkin leaves accessions constituted the majority of the 23 accessions that were graded medium to high NHIV grades, with eight and six accessions respectively. Others were beans (3 accessions), black nightshade (2), local kales (1), spider plant (1), kales (1) and maize (1) (Table 3.1). Table 3.1 below also shows how the individual mineral ranks contributed to the overall NHIV grades for each accession (see Appendix 3.1a to 3.1e for the NHIV grading process and Appendix 3.3 for the full list of NHIV grades for all the accessions analyzed). Three amaranth accessions (S09F30VNU P74, S09F38ENU P70 & S09F40ENU P84) and one local kale accession (S09F33ENU P87) were further singled out for consistently scoring medium to high NHIV grades for two successive seasons.

Table 3.1: Nutrahealth-implied Ionomic Variants grades for highly exceptional and moderately exceptional plant accessions for three consecutive seasons in Esibuye and Vihiga.

	District	SDU section	Accession code	Species	NHIV grade	Ionomic variation content ranks					
						K	Ca	Fe	Sr	Mn	Zn
Exceptionally Core (Highly Exceptional) collections - 1.4%											
1	Esibuye	LFV	L09F15ENU P5	Beans (wairimu)	8	2	4	1	3	1	4
2	Vihiga	LFF	S09F1VNU P91	Spider plant	8	2	4	1	3	1	4
Core (Moderately Exceptional) collections - 14.8%											
3	Esibuye	LBKF	S08F17EEbyNUP468	Pumpkin leaves	7	3	1	5	1	5	5
4	Vihiga	LBKF	S08F7VEmdNUP412	Pumpkin leaves	7	3	1	5	1	5	5
5	Vihiga	LFV	L09F1VNU P118	Pumpkin leaves	7	3	1	4	1	4	5
6	Vihiga	RBKF	S08F1VIkbNUP382	Amaranth	7	3	4	5	3	2	1
7	Esibuye	LBKF	S08F24EEbsNUP492	Pumpkin leaves	6	4	3	2	3	2	5
8	Vihiga	LBKF	S08F8VEmdNUP424	Amaranth	6	4	4	5	3	1	4
9	Vihiga	LBKF	S08F3VIkbNUP557	Solanum	6	2	5	1	5	3	5
10	Esibuye	LBKF	S08F13EEbsNUP450	Amaranth	5	2	5	5	5	2	4
11	Esibuye	LBKF	S08F20EEbyNUP479	Amaranth	5	4	4	5	5	1	5
12	Esibuye	LBKF	S08F23EEbyNUP491	Pumpkin leaves	5	3	2	5	2	4	5
13	Esibuye	LBKF	L09F22ENU P162	Kales	5	4	4	5	4	1	4
14	Esibuye	LFV	L09F14ENU P116	Beans varieties	5	1	4	5	4	4	4
15	Esibuye	LFV	L09F15ENU P3	Beans (zindoli)	5	2	5	5	5	2	4
16	Esibuye	NHBF	S08F16EEbyNUP466	Pumpkin leaves	5	1	5	3	5	5	4
17	Esibuye	NHBF	S09F33ENU P87	Local Kales (6)*	5	3	4	5	4	5	1
18	Esibuye	NHBF	S09F38ENU P70	Amaranth (7)*	5	1	4	5	4	4	4
19	Esibuye	NHBF	S09F40ENU P84	Amaranth (6)*	5	1	5	4	4	4	5
20	Esibuye	RBKF	L09F26ENU P2	Maize	5	1	4	5	4	4	4
21	Esibuye	RBKV	L09F13ENU P147	Amaranth 2	5	2	4	5	4	4	3
22	Vihiga	LBKF	L09F7VNU P128	Solanum	5	2	5	4	4	3	3
23	Vihiga	NHBF	S09F30VNU P74	Amaranth (6)*	5	1	4	5	4	4	4

The higher the grade number, the more superior the nutraceutical variation is in the ionomic variant. See the full list of accessions in Appendix 3.3

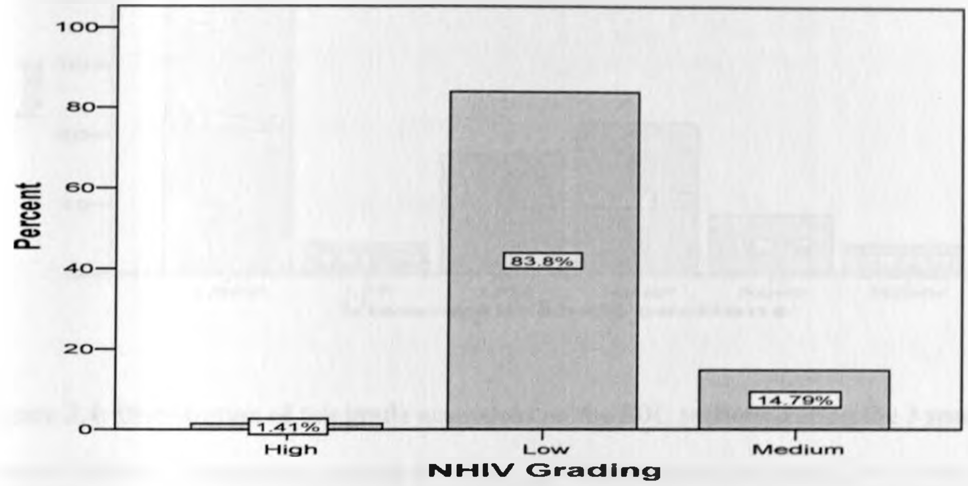


Figure 3.3: Overall distribution of Nutrahealth-implied ionomic Variant (NHIV) grades for all the plant accessions analyzed

Most of the top grade accessions (43%) were found at the left back kitchen yard garden on flat ground (LBKF) section of the SDU. Whereas none was obtained from the sloping area, 22% of the medium to top grade accessions were obtained from valley land and 78% from flat land. Only 22% of the medium and high NHIV grade accessions came from far farm area of the SDU. The rest were found growing either near house (22%) or in the back kitchen garden (56%) (Figure 3.4). The variations in NHIV grades associated with different view-walk sections of the SDU suggest that 'allocationing' and 'locationing' decision factors may be affecting the realization of the nutraceutical implied value of foods by people in TAGEs.

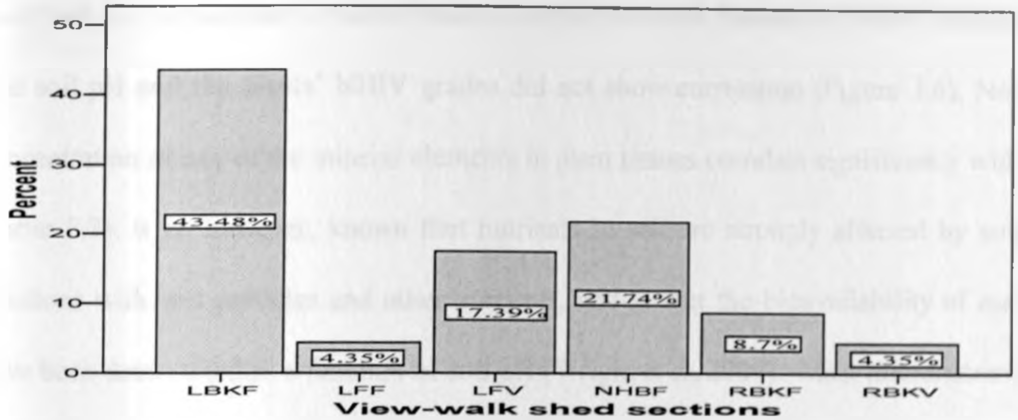


Figure 3.4: Distribution of top grade accessions on the SDU sections during the 3 seasons of study.

Legend:- LBKF = Left back kitchen garden on flat ground; LFF = Left far farm on flat ground; LFV = Left far farm on valley land; NHBF = Near house border farm on flat ground; RBKF = Right back kitchen garden on flat ground; RBKV = Right back kitchen garden on valley land

3.4.2 Plant mineral content in relation to mineral concentrations in the soil

Comparison of mineral concentrations in both soil and plants from the respective sites in 2009 was possible only for K, Sr, and Rb since the MIR spectra for the other mineral elements did not calibrate well to the reference data. No correlation was however apparent (Figures 2.5a to 2.5c). Pearson correlations of mineral element concentrations in soil and plant samples of 2008 were significant only for Zinc (0.258) at 0.05 levels (2-tailed) (Table 2.1). A highly significant Pearson correlation coefficient of 0.940 was observed between the soil concentrations Zn and K suggesting that analysis results for either element may be used to make predictions about the other (Table 3.2). Correlation between the soil properties and plant mineral content may not be apparent in this study because of the genetic differences between ionomes. Such a correlation can only be ascertained in an experiment where one variable (in this case the ionomic variant) is held constant.

3.4.3 Soil pH in relation to Nutra-Health Implied IonomicVariation (NHIV) across farm-types

The soil pH and the plants' NHIV grades did not show correlation (Figure 3.6). Neither did the concentration of any of the mineral elements in plant tissues correlate significantly with the soil pH (Table 3.3). It is, however, known that nutrients in soil are strongly affected by soil pH due to reactions with soil particles and other nutrients, and in fact the bioavailability of many nutrients have been determined as a function of soil pH (Wright et al. 2009). Most micronutrients and P are normally readily available to crops at low pH values and show decreased availability with increasing pH even when their total concentrations in the soil are not low. Lack of correlation in this study can be explained by the fact that it involved different plant ionomes with varying responses to similar environmental conditions.

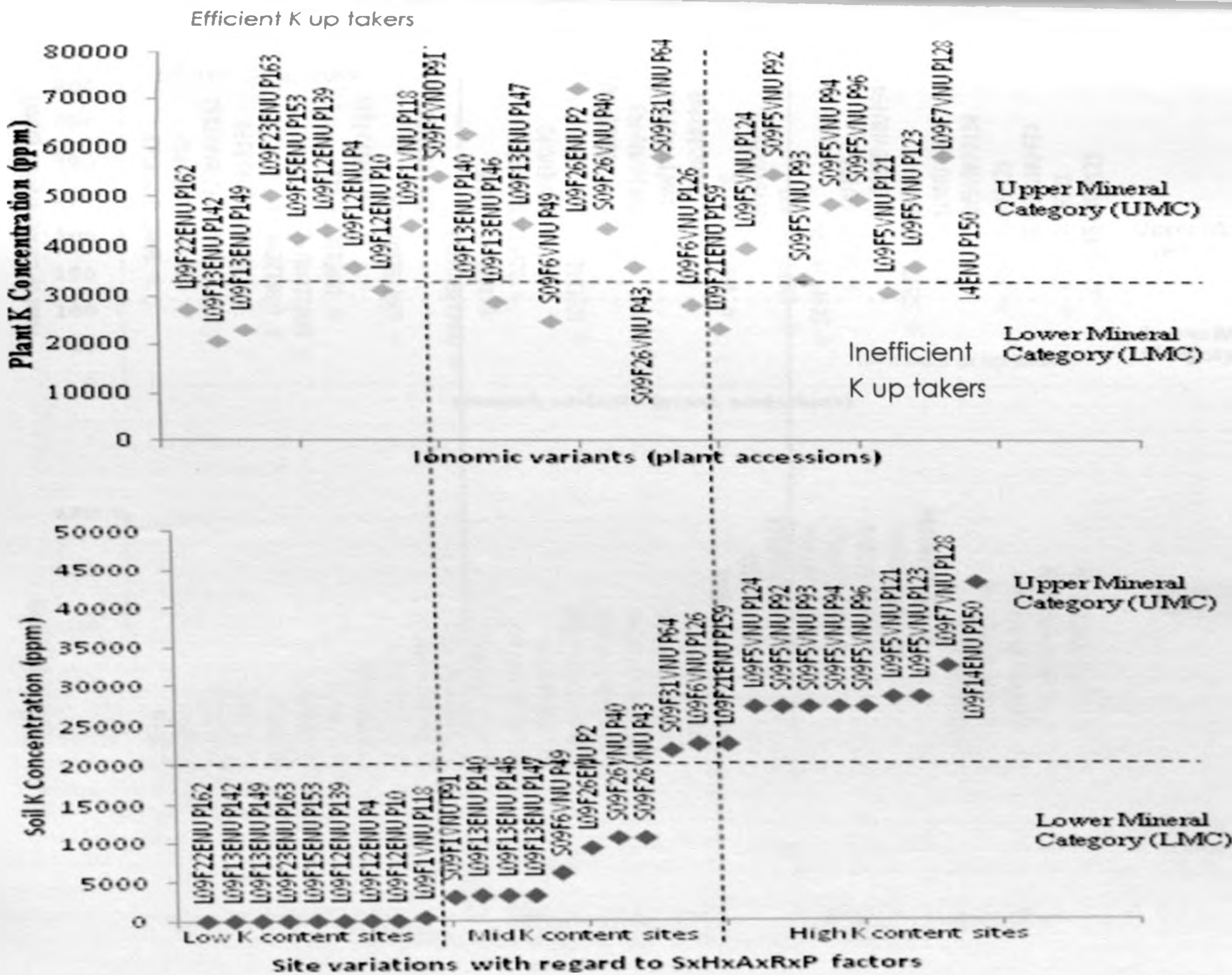


Figure 3.5a: Mapping of potassium (K) Concentration in soil and plants at respective sites for 2009 samples.

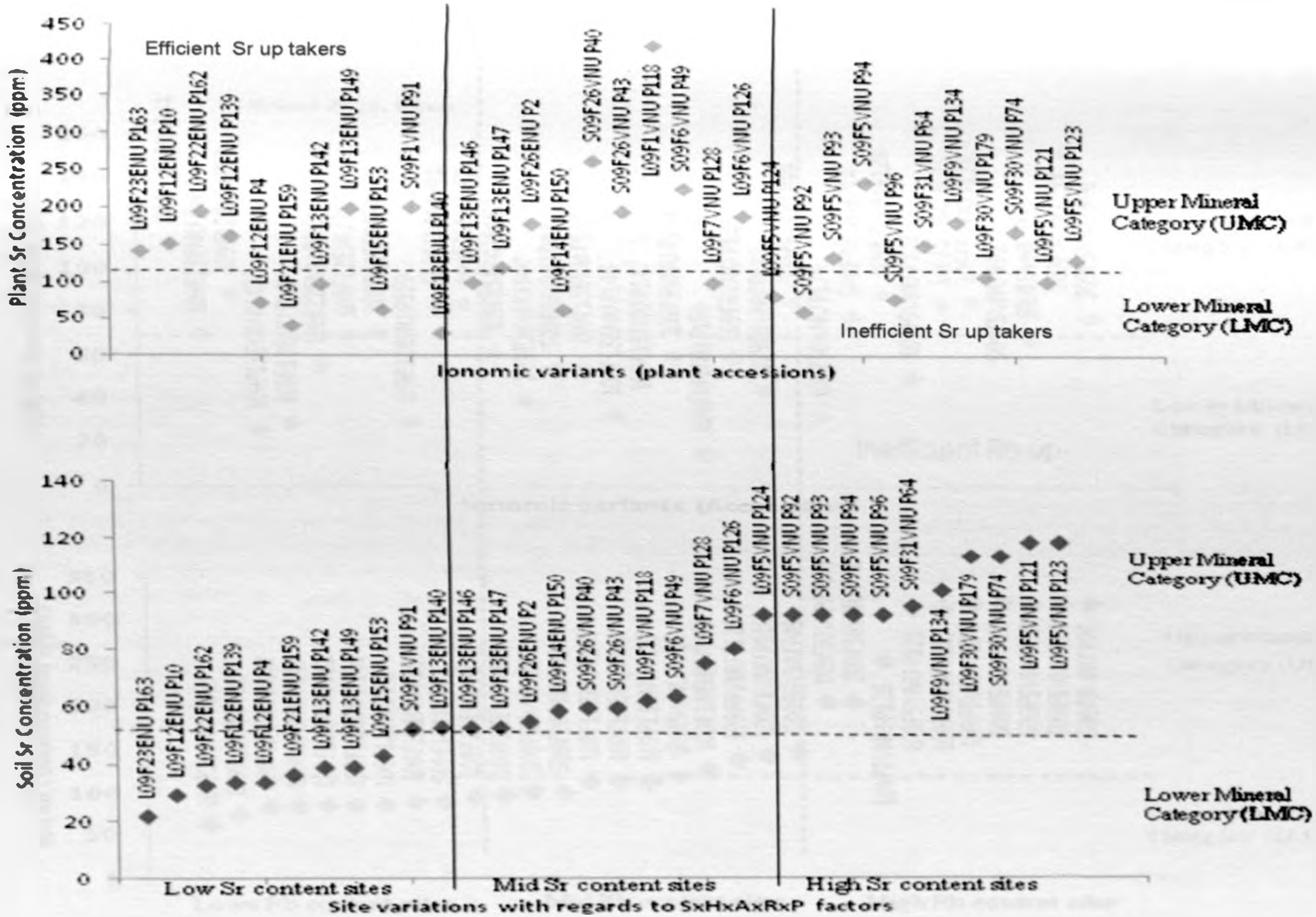


Figure 3.5b: Mapping of strontium (Sr) concentration in soil and plants at respective sites for 2009 samples.

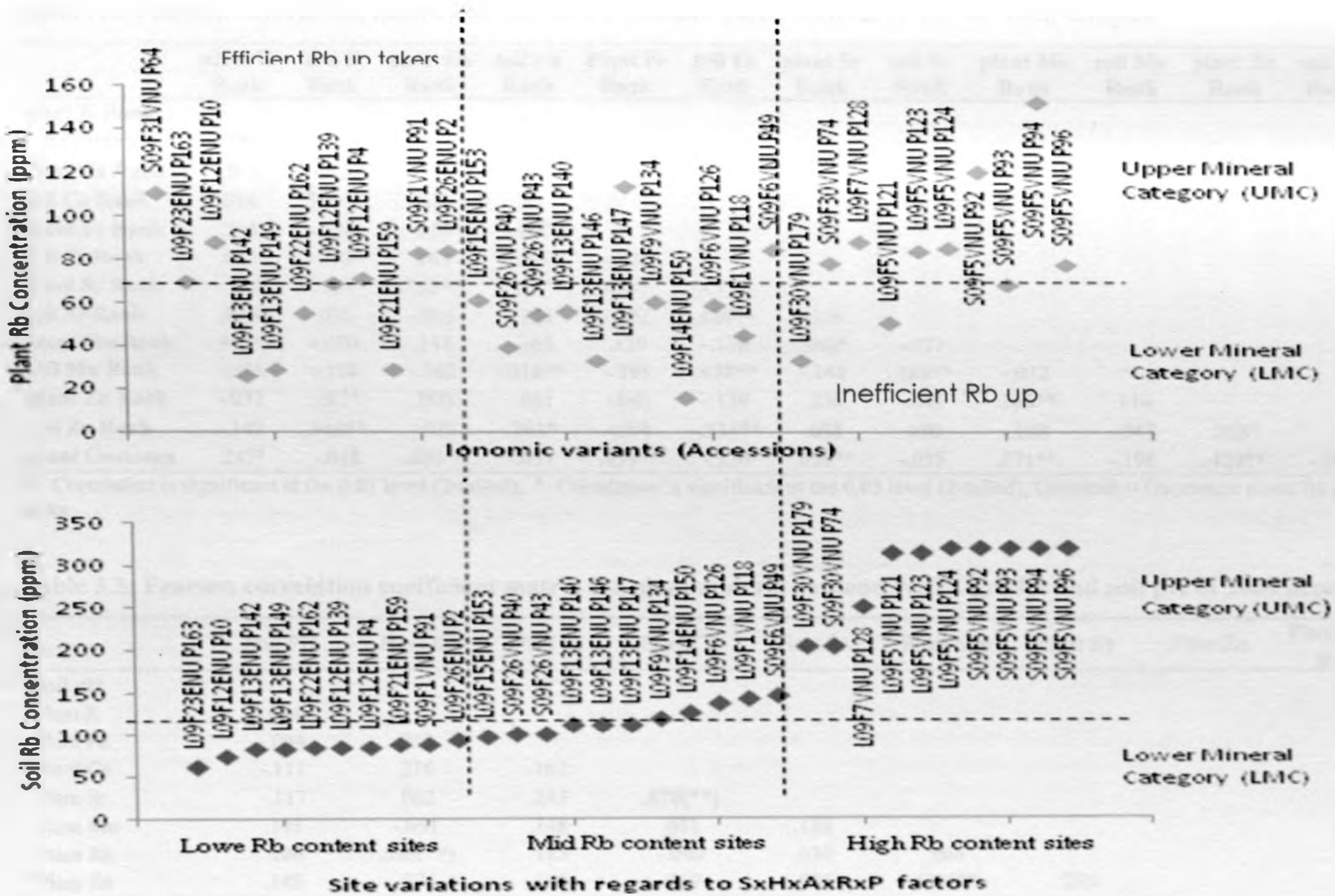


Figure 3.5c: Mapping of rubidium (Rb) concentration in soil and plants at respective sites for 2009 samples.

Table 3.2: Pearson correlation coefficient matrix for soil and plant mineral ranks for 2008 samples

	plant K Rank	soil K Rank	plant Ca Rank	soil Ca Rank	Plant Fe Rank	soil Fe Rank	plant Sr Rank	soil Sr Rank	plant Mn Rank	soil Mn Rank	plant Zn Rank	soil Zn Rank	plant Geomean
plant K Rank													
soil K Rank	-.141												
plant Ca Rank	-.042	.028											
soil Ca Rank	.014	.390**	.041										
Plant Fe Rank	.234	-.185	.013	-.060									
soil Fe Rank	.082	-.312*	.043	-.091	-.126								
plant Sr Rank	-.106	.124	**.732****	.037	-.011	-.110							
soil Sr Rank	.010	.035	-.006	-.159	-.072	**.626****	.059						
plant Mn Rank	-.345**	-.070	.147	-.165	.139	-.178	.268*	-.077					
soil Mn Rank	-.235	-.128	-.162	-.316**	-.191	.478**	-.148	.386**	-.012				
plant Zn Rank	-.037	.262*	.000	-.081	-.040	-.139	.236	-.041	.366**	.114			
soil Zn Rank	-.142	**.940****	-.022	.283*	-.098	-.335**	.088	.080	-.058	-.047	**.258***		
plant Geomean	.247*	-.048	.609**	-.057	.439**	-.130	.658**	-.055	.571**	-.196	.429**	-.035	

** Correlation is significant at the 0.01 level (2-tailed), * Correlation is significant at the 0.05 level (2-tailed), Geomean = Geometric mean for all the six mineral ranks

Table 3.3: Pearson correlation coefficient matrix for plant mineral content, NHIV grades and soil pH of 2009 accessions

	Soil PH	Plant K	Plant Fe	Plant Ca	Plant Sr	Plant Mn	Plant Rb	Plant Zn	Plant NHIV grade
Soil pH									
Plant K	.054								
Plant Fe	-.084	.255							
Plant Ca	-.111	.216	.162						
Plant Sr	-.117	.062	.243	**.878(**)**					
Plant Mn	.145	-.051	.148	.051	.125				
Plant Rb	.126	.500(**)	.115	-.040	.036	.063			
Plant Zn	.148	.276	.290	.069	.036	.431(**)	.295		
Plant NHIV grade	-.062	.611(**)	.536(**)	.587(**)	.551(**)	.388(*)	.317	.536(**)	

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

The left side of the far-farm on the top & Valley topographies

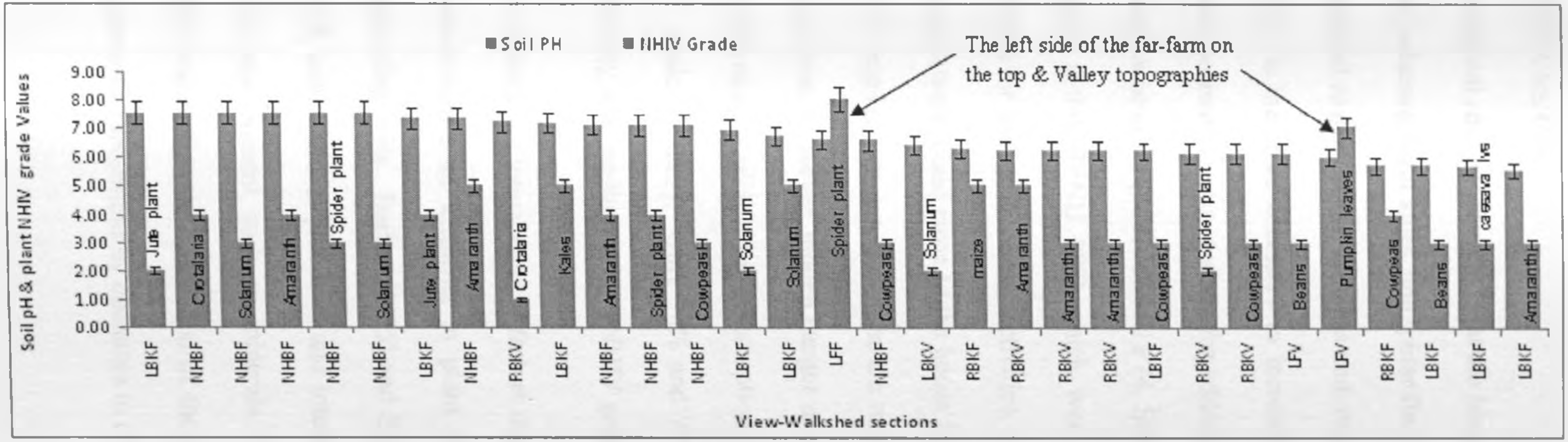


Figure 3.6: Comparison of soil pH with plant NHIV grades at various sections of the Esibuye and Vihiga smallholder SDUs during the year 2009.

Legend: LBKF = Left back kitchen garden on flat ground; LBKS = Left back kitchen garden on sloping ground; LBKV = Left back kitchen garden on valley land; LFF = Left far farm on flat ground; LFS = Left far farm on sloping ground; LFV = Left far farm on valley land; NHBF = Near house farm border on flat ground; NHBS = Near house farm border on sloping ground; RBKF = Right back kitchen garden on flat ground; RBKS = Right back kitchen garden on sloping ground; RBKV = Right back kitchen garden on valley land

The error bars indicate 5% error of the soil pH and plant NHIV grade values.

3.5 DISCUSSION

Nutraceutical analysis revealed that the less popular traditional species such as amaranth, pumpkin leaves, solanum, local kales, and spider flower had better nutraceutical value compared to the more popularized maize, beans, bananas and sweet potatoes. Awareness creation through promotional activities is therefore necessary to increase the production and use of the more nutraceutically valuable accessions as a strategy for addressing the problems of hidden hunger in TAGEs. Three amaranth accessions (S09F30VNU P74, S09F38ENU P70 & S09F40ENU P84) and one local kale accession (S09F33ENU P87) which were found to be nutraceutically superior are potential candidates for such promotional activities. The fact that most of the medium and high NHIV grade accessions were found close to the house (in the mid-farm and near house sections) is good news because crops grown near the house are more frequently used for food than those grown in the far farm sections. However, hidden hunger may still be a problem in the region because most of the plant accessions available for consumption belong to the reserve category (i.e. they are of the low NHIV grade corridor). Only 10% and 22% of the locally produced foods in 2008 and 2009, respectively, had medium to high NHIV grade.

The complexity of interactions of factors that affect plant nutrition can explain the observation that the concentration of elements in plant tissues was not significantly related to that in the corresponding soils. Barber (1995) and Brady and Well (2002), have described how biological, physical, and chemical processes and interactions among many different components of the soil and the environment such as minerals, air, water, organic matter and the plants inherent characteristics affect the realization of the optimum genetic potentials of any accession. So the management interventions by operators to ensure the optimum conditions required for any superior plant accession prevails is crucial. The requisite ideal conditions can be achieved through appropriate land husbandry practices that include slope management, soil and water conservation and management, addition of soil amendments and plant nutrients, agro-biodiversity control, and species' allocationing on the SDU.

3.6 Conclusions and recommendations

Three amaranth accessions (S09F30VNU P74, S09F38ENU P70 & S09F40ENU P84) and one local kale accession (S09F33ENU P87) were found to be nutraceutically superior. It is recommend that they should be given further research and development attention by national and international research institutions. This study has also shown that most of the popular and frequently utilized foods in the study area had less nutraceutical value compared to some of the less popular ones. It is, therefore, necessary to target the popular species for improvement in nutritional value, and the less popular, but high value species like amaranth, pumpkin leaves, solanum, local kales, and spider flower for promotional activities to increase their visibility and volume.

CHAPTER FOUR

Topo-Positional mapping of the State of Smallholder Agro-phyto-diversity as a SHUB-Ionomic Diversity Unit, for Back-forward Utilization and Conservation in Traditional Agro-Ecologies of Esibuye and Vihiga

4.1 Abstract

Continued land subdivision has resulted into reduction of farm sizes in general to less than five acres which endangers stability in small scale genetic diversity systems. Changes in the management of farm resources to suit new demands under the changed resource use circumstances have seen a shift in the on farm phyto-diversity with introduction of new commercial species; neglect of indigenous crop species and a net reduction in the overall agro-phyto-diversity. The smallholdings serving as human ecologies as well as sanctuaries of primary agro-phyto-diversity for production and consumption are herein referred to as Smallholder Utility-Based Ionomic Diversity Units, or simply as SHUB-Ionomic Diversity Units (SDUs). An SDU is defined as a smallholding farm or a homestead-farm habitat described in terms of utility based micronutrient dietary diversity, from where a household derives its food from a range of genetic diversity 'allocationed' or 'locationed' at specific sections as determined by factors such as proximity to the house, the topography of the land, species' popularization and security requirements. Subsistence SDU social formations are herein referred to as traditional agro-ecologies (TAGEs). The TAGEs are made even more fragile when any of the genetic diversity therein is not subjected to a back- (conserve to use) and forward- (use to conserve) management principle. Non-traditional land use changes that tip the back-forward equilibriums have also resulted in the decline of agro-phyto-diversity in TAGEs most of which still serve as the primary sources of household subsistence

needs. This raises the questions as to whether the phyto-dietary diversity in quantity and/or quality as accessed from the TAGEs have been equally affected by the increasing land fragmentation and the soil nutrient fluxes including the narrowing of the SHUB-Ionomic genetic base. This study thus sought to establish the state of smallholder farm as a resilient SHUB-Ionomic diversity unit with a top grade promise worth conserving for use with less worry in traditional agro-ecologies of Esibuye and Vihiga and to map the nutra-health implied ionomic variations (NHIVs) in the SHUB-Ionomic diversity units as an indicator of how households access nutraceutically important plant accessions for food and health. A survey involving 30 women smallholder farm operators was carried out using questionnaires and visual observations. Plant accessions grown or preserved in the SDUs to provide food for the family were analyzed and graded on the basis of their mineral micronutrient content as Nutra-Health Implied Ionomic Variant (NHIV) grades, and their positions relative to the view and walk landscape positions depicted in an SDU map of the TAGEs as NHIV grade positions.

It was found that tastes and preferences in TAGEs were changing and indigenous foods were being dropped in favour of exotic and commercial species and varieties thus weakening the resilience of the SHUB-Ionomic diversity. Furthermore the agro-phyto-diversity in broad terms in smallholder farms appeared to be reducing with popularization of a few staple and commercial species at the expense of a more diversified and conserved production system. Most of the accessions with medium to high NHIV grades were found in the flat areas in mid-farm sections of the SDUs. These changes could in short term have implications in the nutraceutical wellbeing of the household members.

4.2 Background

The ever increasing population and changes in land use have resulted into smaller sizes of farm holdings. This reduction in the sizes of smallholdings has necessitated changes in their management practices. The traditional role of these ecologies as the main sources of food and income as well as providing space for construction of residential houses for the family and allow room for other cultural activities however is expected to continue. As part of the new management strategies, SDU operators now concentrate on the production of a few popular crop species while neglecting most of the traditional species. Reduction in the agro-phyto-diversity in smallholder farms (or TAGEs in this context) has been also observed by various authors (Abukutsa-onyango, 2008; Mitra and Pathak, 2008; and Vorster et al. 2008). This raises the questions as to whether the phyto-dietary diversity in quantity and/or quality accessed from the TAGEs are being affected by the increasing land fragmentation, soil nutrient fluxes, and staple food narrowing of the genetic base? What is the current status of agro-phyto-diversity in TAGEs? What are the most popular crop species as food in TAGEs? What indigenous/traditional crop species are being depopularized? Are some indigenous/traditional crop species being conserved? Which new species are being popularized? From where are the newly adopted crop species being sourced and for what purpose are they being adopted? Is the SDU an important source of food for the people living in TAGEs? How are the various plant species allocationed/locationed on the SDU sections? Does the location of a crop species at a particular SDU section affect its nutra-health implied value or the realization of this value by the household members?

These pertinent questions need to be answered in order to be able to more effectively address the problem of hidden hunger in TAGEs. Phyto-dietary diversity and its quality are of particular importance here in view of the micronutrient challenges for lack of minerals and vitamins that are emerging in impoverished TAGEs. The objectives of this study were to establish the state of smallholder farm as a resilient SHUB-Ionomic diversity unit with a top grade promise worth conserving for use with less worry in traditional agro-ecologies of Esibuye and Vihiga and to map the nutra-health implied ionomic variant (NHIV) grades in the SDUs as an indicator of how households access nutraceutically important plant accessions for food and health. While breeding for quality has worked to improve food production especially for more commercially oriented farmers who can afford the necessary inputs and high level management, the small farmers in TAGEs have an economic handicap. Already, they may have lost a number of their traditional crop varieties and indigenous species of which dietary diversity and quality may have gone with them resulting in hidden hunger due to loss of type I and type II micronutrients. Classification of nutrients as type I or type II has been explained by Watson, (1998) in relation to how the body responds to dietary deficiencies. Whereas specific physical signs are shown for deficiency of type I nutrients such as iron without affecting growth or body weight, the body responds to deficiency of type II nutrients such as zinc by stoppage of growth and loss of weight without specific deficiency signs since tissue concentrations are preserved.

4.2.1 Indigenous on farm agro-phyto-diversity as a basis for popular utilization that promotes conservation and value addition.

A number of studies have been made on land use changes and the trend of utilization of traditional crops as affected by various factors. Studies in the Southern Africa Development Cooperation Community region have shown that there is a decline in the utilization of traditional vegetables because of the replacement of the indigenous species by the deliberate introduction of exotic vegetables which are well commercialized and studied (Attere, 1990). Abukutsa-Onyango (2008) further noted that the loss of on farm phyto-diversity in smallholder agro-ecologies in Kenya was due to general neglect and inadequate promotion of the production and consumption of African Indigenous Vegetables (AIVs). Mitra and Pathak (2008) reported that the availability of fruits and vegetables on the farm was declining while at the same time impoverished farmers were not able to afford to buy them from the market. A study by the National Museums of Kenya revealed that people especially the youths were despising their traditional foods in favour of exotic or introduced foods (UNESCO, 2008).

As reliance upon staple food cropping increased, dietary diversity diminished. Mnzava (1995) argued that, as food choice and hence dietary diversity diminished the probability of getting all essential nutrients obtainable from underutilized/neglected/or orphaned indigenous plants also diminished thereby increasing vulnerability to malnutrition and hidden hunger especially among the poor, the sick, pregnant women and children.

The underlying hypothesis in respect of this study was that phyto-dietary diversity and quality in TAGES as primary SHUB-Ionomic Diversity Units and destinations may not have suffered reduction given the current farm land-use patterns and the presence and positions of 'house-yard'. A house-yard is here taken as physical entity of a homestead that is positioned on a near-farm that is sandwiched by a mid- or kitchen garden and is distantly separated from the far-farm.

4.2.2 The SHUB-Ionomic quality implications of 'allocationing' and 'locationing' land use decisions in SDUs

Management decisions that operators of SDUs have to make are influenced by a complex interaction of diverse factors both internal and external. The interactions have been analyzed by FAO (1995) using the farm household as the primary unit of analysis of farm-level decision making (See section 2.4 in Chapter two). Among other factors, the 'allocationing' and 'locationing' decisions of land use are often based on the view-walkshed morphology of the farm which to a large extent also affects nutrient fluxes. The decisions therefore affect the SHUB-Ionomic quality implied by the food available from the SDUs.

4.3 Objective

To determine the state of agro-phyto-diversity, and map the topo-positional nutrahealth-implied ionomic variants in smallholder traditional agro-ecologies of Esibuye and Vihiga.

4.4 Justification

If on-farm indigenous phyto-diversity is popularized by a vigorous use, it will encourage conservation, and vice versa, rigorous use may be in part primed by value addition strategies, among them the micronutrient quality that may give them a nutraceutical attribute particularly under the SHUB-Ionomic diversity units.

It is for the above reasons that a focus is warranted on determination of agro-phyto-diversity circumstances such as the prevailing crops, introductions, near disappeared crops, purposes for which they are grown, their abundance, respective NHIV grades and placements on the SDU sections

4.5 Materials and Methods

4.5.1 Determination and delineation of sections of SHUB-Ionomic Diversity Unit

Thirty women operated smallholder farms or SDUs in Esibuye and Vihiga TAGEs were sampled using the multistage sampling design. An SDU was delineated into 15 sections based on the view-walkshed referencing criteria (i.e. unit distance from the house by farm land use topographies). There were five viewshed sections described as near house border (NHB), left side kitchen yard garden (LBK), left side far farm (LF), right side kitchen yard garden (RBK) and right side far farm (RF) juxtaposed with three walkshed sections namely upland/flat land use type (F), sloping land use type (S) and valley land use type (V). 15 view-walkshed sections were thus delineated on each SDU thus: A near-house /centre View: 1 view section by the upland walk, sloped walk and the valley walks=3; the left & right Mid-farm views from the farm house: 2 x 3=6; the left & right far farm views: 2 x 3= 6.

4.5.2 Mapping of agro-phyto-diversity and NHIV grade positions on the SDUs

Data on agro-phyto-diversity was processed by inventorying all plant species used for food across the 15 sampling sections on each SDU unit on a free-call basis (i.e. as found where found). They were categorized into six cultivation groups (culti-groups) namely: cereals (C), vegetables (V), roots and tubers (R), snacks and minor crops (S), tea and coffee (T), and fruits (F). Agro-phyto-diversity maps showing the sections of the SDUs and the corresponding plant species and crop categories were prepared and then translated into NHIV grade maps on the basis of laboratory analysis results as described earlier in Chapter three.

4.5.2.1 The mapping basis

Mapping of agro-phyto-diversity occurrence in the various SDU sections was done to capture differences due to the viewshed positions, differences due to the walkshed positions and the interaction effect between the view-walk positions. Three kinds of agro-phyto-diversity maps were prepared on the bases of:

1. Distribution of plant species and culti-groups on the SDU sections.

The abundance of the different culti-groups were represented as absolute numbers corresponding to the number of plant accessions of a specific culti-group found at specific SDU sections on the onion shaped mapping models alongside bar graphs showing relative culti-group occurrences as percentages of the total number of respective culti-group accessions.

2. The Mineral Micronutrient (MMN) densities by each element (ppm).

The accessions were labelled with concentrations of each element in parts per million and mapped as above.

3. Nutraceutical or Nutrahealth-implied Ionomic Variation (NHIV) among accessions.

Accessions were considered as ionomes in terms of their mineral nutrient and trace element composition. The accessions were labelled with their NHIV grades and their positions on the View-walkshed sections of the SDU mapped. The accessions were hence delimited into the Less exceptional Nutrahealth implied Ionomic Variants (L-NHIV); Moderately exceptional Nutrahealth implied Ionomic Variants (M-NHIV); and the Highly exceptional Nutrahealth implied Ionomic Variants (H-NHIV) corresponding to the 'extra core', 'core' and 'reserve' collections respectively. The description of plant accessions as belonging to 'core' or 'reserve collections has previously been done by Frankel, 1982. According to the author, the former group comprises collections that have special value characteristics that distinguish them from the latter collections. Unlike the core collections, reserve collections can be lumped together without risking the loss of any known special characteristics of prime interest.

4.5.3 Determination of Agro-Phyto-diversity and other land use management decision factors

Agro-Phyto-diversity Directed (APD) questionnaires (Appendix 4.1) were administered to the smallholder women operators to capture data regarding land use patterns and management decision factors related to agro-phyto-diversity abundance and positioning on the SDU sections.

4.5.4 Crop popularization ranking procedure

Operators were asked to list all the crops found on the farm in order of popularity and use frequency, from the most popularized and used crop species to the least popular and underutilized. A ranking procedure was developed by the investigator (Appendix 4.2) and used to derive an overall ranking for all the crops in the Kenyan eco-region sub-basin study sites. Since the SDU with the highest agro-phyto-diversity had 10 species in total, individual ranks by women SDU operators were scored on a scale ranging from 1 to 10 for the least popular crop species to the most popular crop species respectively on a pro-rata basis. The total points scored by any crop species was found by summing all the points scored at all the SDUs. The percent score for each species was then calculated on the maximum possible points that could have been scored in an ideal situation where all the SDUs had the same number of crop species. If a hypothetical situation was assumed whereby each of the 30 SDUs had the same 10 plant species, and one particular species was ranked first in all of the SDUs then that species would earn the maximum possible ranking score of 300 points (i.e. rank 1 x 10 points x 30 SDUs = 300 points) which would be equivalent to 100%. Thus the percentage popularization score for any accession was calculated as:

$$\text{Percent score} = \frac{(\text{ Points scored}) \text{x } 100\%}{300}$$

4.5.5 Statistical analysis procedures.

Statistical analyses were conducted on treatment means using the t-test and F-test procedure of SPSS software version 12.0 and the Microsoft Excel data analysis functions. Analysis of variance tables were prepared for each response variable investigated (Appendix 4.3). Error bars were used with bar charts to indicate potential error amount or uncertainty at 5% of the value of each data point.

4.6 Results

4.6.1 Crop diversification trends

Figures 4.1, 4.2, and 4.3 below show maintained, newly adopted and dropped crop species respectively, ever since the farmers settled in the area, scaled according to the number of SDUs in a reducing scale from group 'A' to group 'D'. The scaling gives an indication of the extent of conservation, adoption, and abandonment of the species by the smallholder farmers in Esibuye and Vihiga TAGEs. Group 'A' crops in both figures 4.1 and 4.2 are comprised of maize, bananas, and beans giving an indication that they are highly regarded as important food crop species that the farmers in the study area would not want to lose but rather improve. African indigenous crops such as cassava, finger millet, bulrush millet, sorghum and sweet potatoes were highly scaled among the abandoned crops (Figure 4.3).

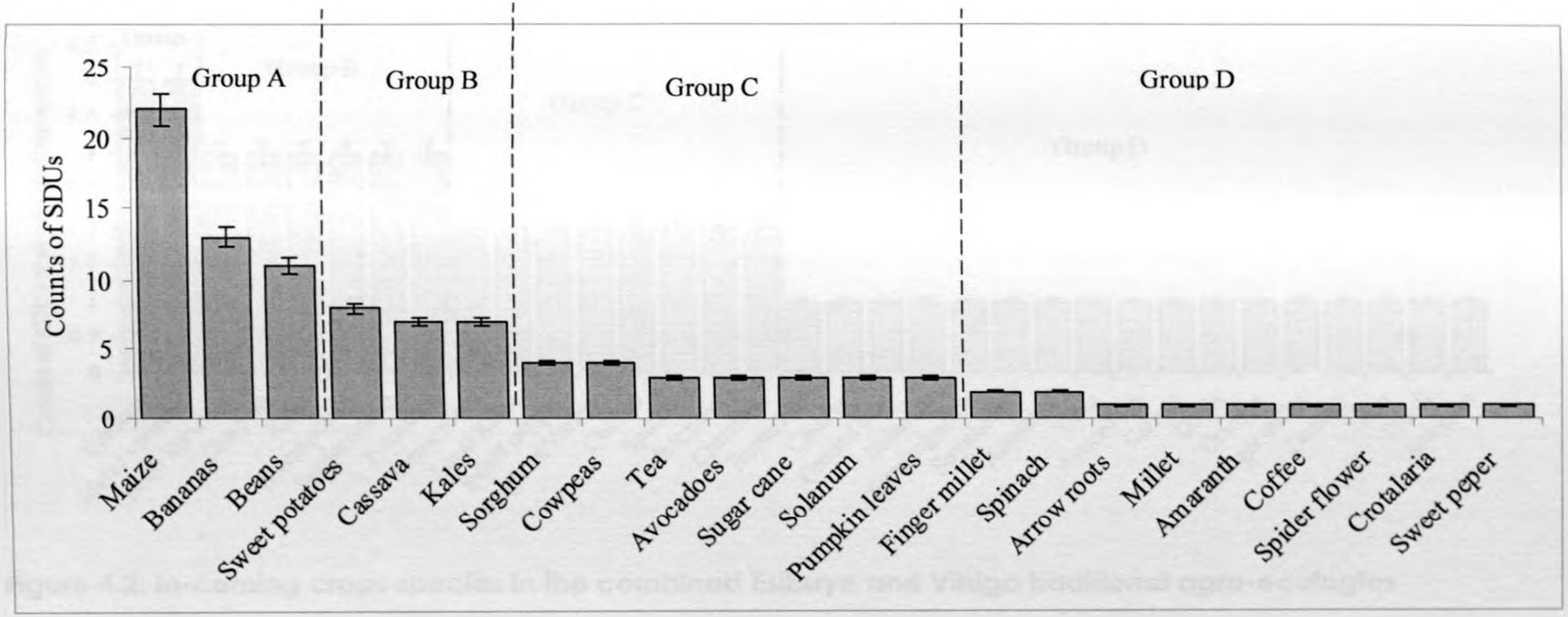


Figure 4.1: On-going crops that had continued being grown in both Esibuye and Vihiga SDUs

Group A – Most conserved crop species; Group B – Well conserved crop species; Group C – Moderately conserved crop species; Group D – Less conserved species

The error bars (I) indicate 5% error of the number of SDUs that had sustained producing the specified crop species

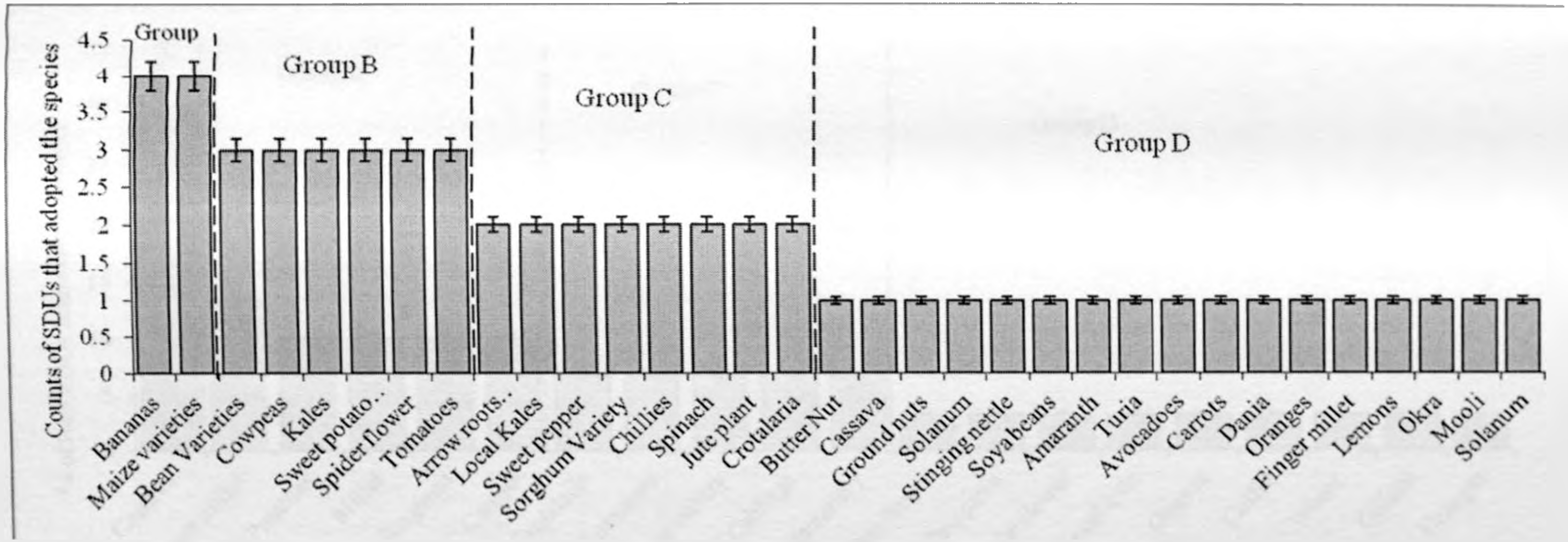


Figure 4.2: In-coming crops species in the combined Esibuye and Vihiga traditional agro-ecologies

Group A – Most introduced crop species; Group B – Highly introduced crop species; Group C – Moderately introduced crop species; Group D – Least introduced crop species

The error bars (I) indicate 5% error of the number of SDUs that had adopted the specified crop species

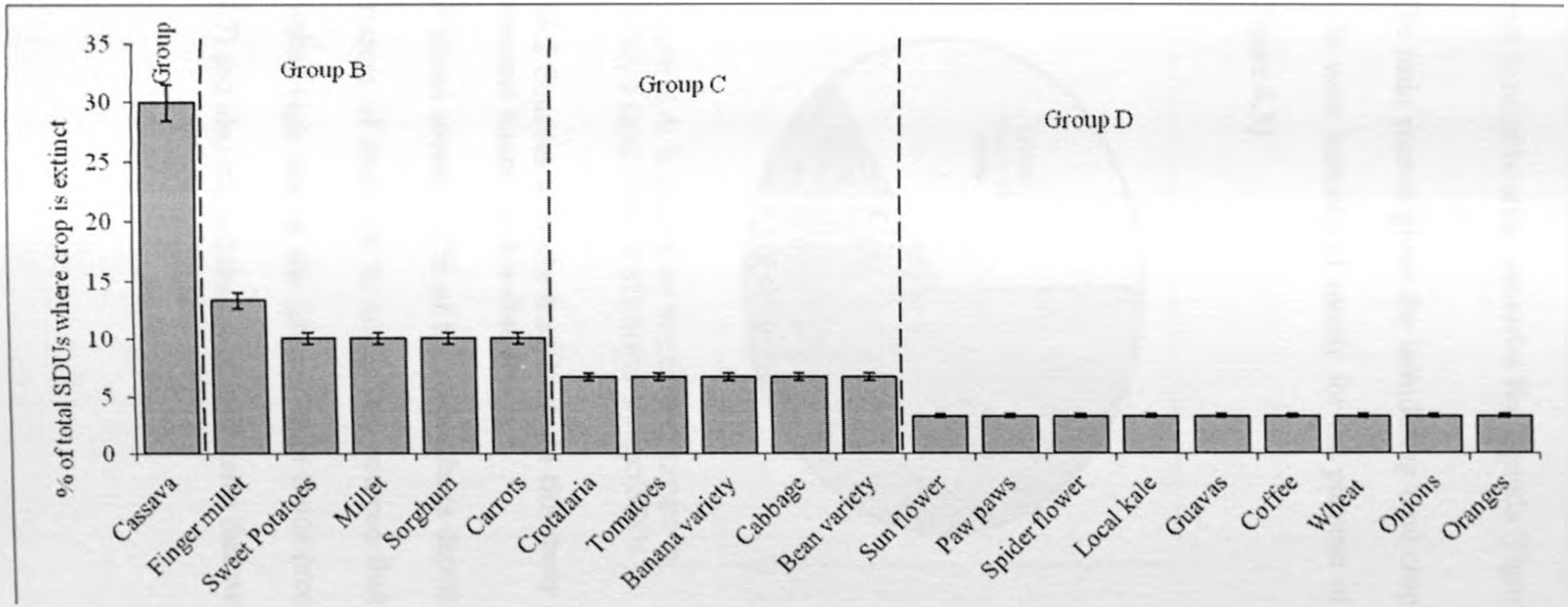


Figure 4.3: Disappeared crops from the Esibuye and Vihiga traditional agro-ecologies

Group A – Most gone crop species; Group B – Highly gone crop species; Group C – Moderately gone crop species; Group D – Little gone crop species

The error bars (I) indicate 5% error of the number of SDUs from where the specified crop species had disappeared

Most of the newly introduced crops were obtained from market (48.4%), 19.4% were obtained from neighbours whereas the rest (34%) were from other sources such as research institutions, NGOs, agricultural extension agencies and from friends who lived in other parts of the country or even in neighbouring countries like Uganda (Figure 4.4).

The main reason given for introducing new crops was to provide food for the household (61%), 31% were introduced mainly for the purpose of sale and 3% were brought in for medicinal use (Figure 4.5).

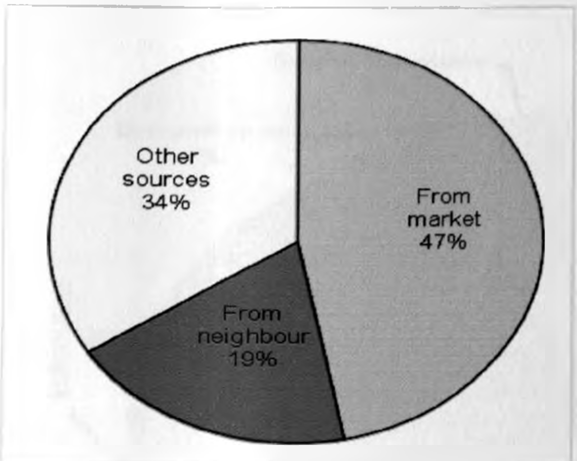


Figure 4.4: Sources of in-coming crops in Esibuye and Vihiga SDUsand Vihiga SDUs

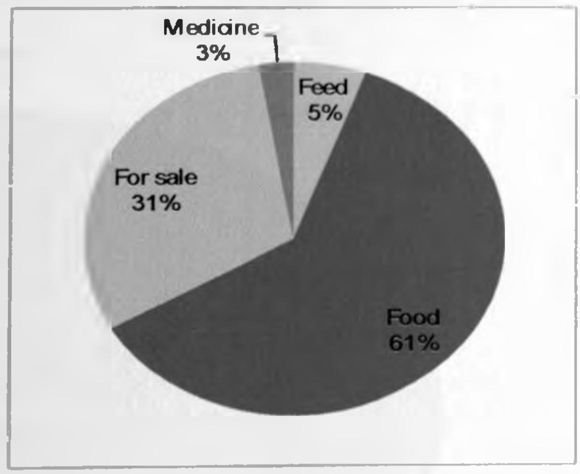
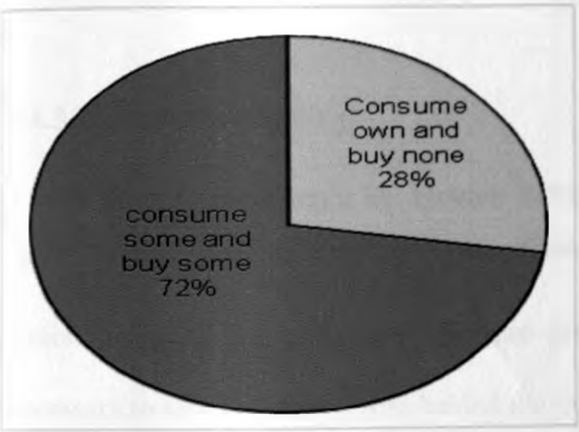


Figure 4.5: Purposes of in-coming crops in Esibuye and Vihiga SDUs

4.6.2 Sources of main food items in the study sites and prospects they render for the SHUB-Ionomic based food inclusions.

Whereas seventy 72% of the respondents depended on both the farm and the market as the main sources of food, 28 % exclusively sourced their major foods from the farm (Figure 4.6). Maize ranked high among the farmers' own foods produced on the farm for family consumption (Figure 4.7) and also topped the list of food items that were purchased from the market (Figure 4.8).



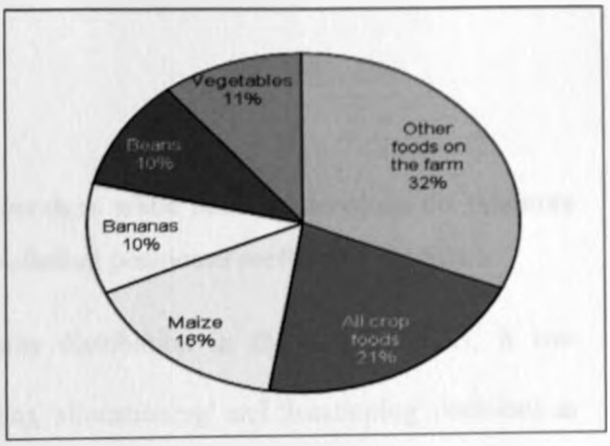


Figure 4.6: Main food sources for households in Esibuye and Vihiga sites

Figure 4.7: Crop commonness on the farms for households' own consumption

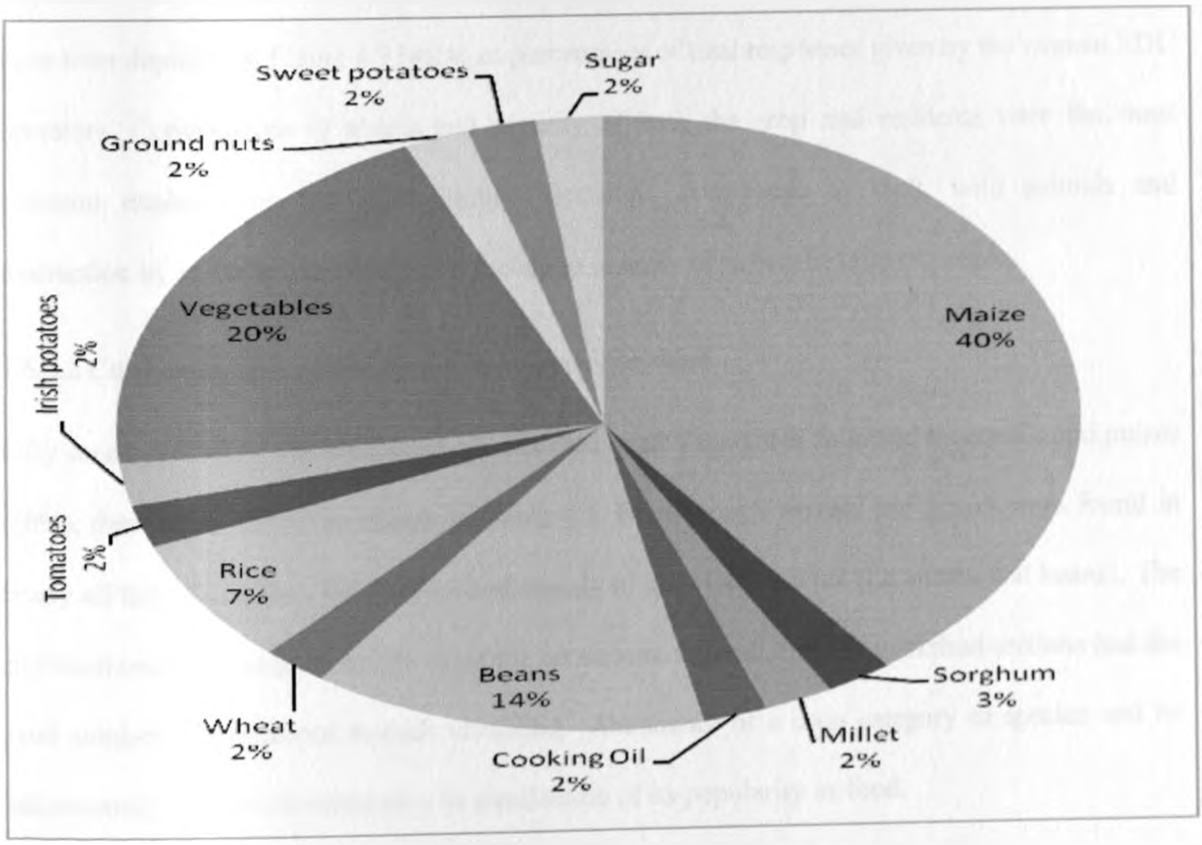


Figure 4.8: Major food purchases by households in Esibuye and Vihiga sites

4.6.3 The mapping findings

4.6.3.1 Factors considered by Women SDU operators while making decisions on resource 'allocationing' and 'locationing' on the View-Walkshed positional sections of the SDUs

Before mapping the agro-phyto Ionomic diversity distribution in the SDU sections, it was necessary to establish the reasons behind the existing 'allocationing' and 'locationing' decisions as a basis for understanding the implications of existing distribution of plant species and their implied respective NHIV grades to the nutraceutical implied wellbeing of the family members. The reasons have been depicted in Figure 4.9 below as percentages of total responses given by the women SDU operators. Convenience of access and security of both the crop and residents were the most common explanations for 'allocationing' decisions. Avoidance of theft, wild animals and destruction by children and livestock all relate to security of either the crop or people.

4.6.3.2 Culti-crop occurrence by the farm-type positions

Fifty seven percent of the accessions encountered were Vegetables followed by cereals and pulses (20%), then Fruits (13%) as shown in Table 4.1. Even though cereals and pulses were found in nearly all the SDUs, they were comprised mainly of only two species (i.e. maize and beans). The mid-farm section contained 65.3% of all the accessions. Overall, the flat walkshed sections had the most number of accessions in each viewshed. Abundance of a crop category or species and its 'allocationing' in the viewshed may be a reflection of its popularity as food.

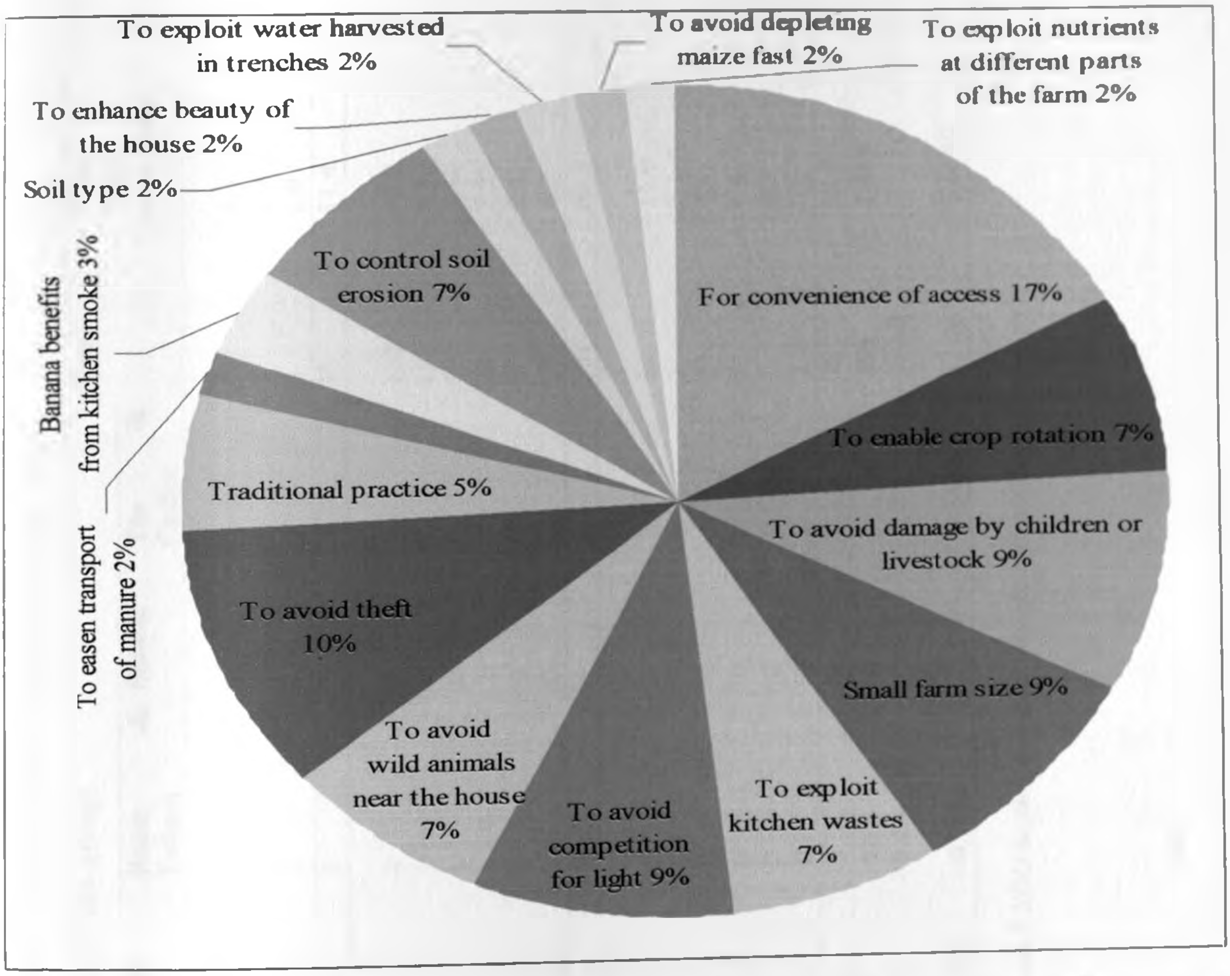


Figure 4.9: Explanations for allocationing plant types at specific View-walkshed sections on the SHUB-Ionomic Diversity Unit (SDU)

Table 4.1: Crop category abundance and allocationing index on the SHUB-Ionomic Diversity Units.

View-walkshed sections as source of plant accessions	Number of accessions per Crop category (Culti-group)						Total	% of Total accessions
	Vegetables	Cereals & Pulses	Fruits	Roots & Tubers	Snacks	Tea & Coffee		
I. Near-house farm								
Flat	12	0	5	0	0	0	17	5.5
Slope	2	1	2	2	2	0	9	2.9
Valley	0	0	7	1	1	0	9	2.9
Sub-total	14	1	14	3	3	0	35	11.4
II. Mid-farm								
Left Flat	113	4	7	3	3	0	130	42.2
Left Slope	4	1	8	1	1	0	15	4.9
Left Valley	7	1	3	1	0	0	12	3.9
Right Flat	13	6	1	1	1	1	23	7.5
Right Slope	3	2	2	1	0	0	8	2.6
Right Valley	6	3	2	1	0	1	13	4.2
Sub-total	146	17	23	8	5	2	201	65.3
III. Far-Farm								
Left Flat	11	14	2	5	0	2	34	11.0
Left Slope	0	6	0	0	0	1	7	2.3
Left Valley	5	17	0	0	0	1	23	7.5
Right Flat	0	4	1	0	0	0	5	1.6
Right Slope	0	1	0	0	0	0	1	0.3
Right Valley	0	2	0	0	0	0	2	0.6
Sub-total	16	44	3	5	0	4	72	23.4
Total	**176**	**62**	**40**	**16**	**8**	**6**	**308**	**100.0**
% of total accessions	57.1	20.1	13.0	5.2	2.6	1.9	100.0	
Confidence Level (95%)	15.7170	2.7836	1.5334	0.7681	0.570	0.3502	17.4631	5.6699

The body of the table contains the number of plant accessions at each SDU section grouped into six categories (culti-groups)

Table 4.1 above also shows agro-phyto-diversity distributions observed in the various sections of the SDUs. The mid-farm type had the highest number of encountered accessions (201) out of which the majority were vegetables (146 accessions). Both far-farm and near-house types had the least number of vegetable accessions. Mid-farm in this arrangement is the kitchen (backyard) segment which explains the large numbers of accessions shown. The far-farm had 23.4% of all accessions whereas the near house had 11.4%. Like in the mid farm position, the near house position was dominated by vegetables and fruits consisting of 14 accessions each, out of 35 accessions found in the near house farm type.

The agro-phyto-diversity mapping of vegetables, cereals, tea & coffee, roots & tubers, fruits and snacks culti-groups on the SDUs have been shown in Figures 4.10 to 4.15 respectively. Vegetables were mainly found at the back kitchen yard garden especially on the left side of the farm house (Figure 4.10). Out of the total of 176 vegetable accessions inventoried, 139 or 79% were found at the mid-farm section (Back Kitchen yard garden) out of which 113 or 64% were found at Left Back Kitchen yard Flat garden (LBKF) section of the SDU. It can also be seen that out of 15 SDU sections, vegetable accessions were found in 10 sections.

Cereals and pulses were found on 13 out of the 15 view-walkshed defined sections of the SDU. The majority of cereals and pulses accessions (71% or 44 out of 62) were found in the far-farm section distributed as: LFF-22.6%, LFS-9.7%, LFV-27.4%, RFF-6.5%, RFS-1.6%, and RFV-3.2%. The near house border had only one cereal accession. Those found on the sloping land at all the five viewshed defined sections constituted 17% whereas the flat and the valley had 45% and 39% respectively (Figure 4.11).

Tea & coffee were found on 5 out of the 15 view-walkshed sections. 67% of all the tea and coffee accessions were found in far-farm section whereby 33% were on flat land. Slope and valley lands each had 17% (Figure 4.12).

Roots & tubers were found on 9 out of the 15 view-walkshed sections and 9 out of 16 accessions (i.e. 56%) were grown on flat land. The mid-farm section comprised of LBKF, LBKS, LBKV, RBKF, RBKS and RBKV had 50% of the root and tuber accessions (Figure 4.13).

Snacks or Minor crops were found on 5 out of the 15 view-walkshed sections mainly in the near house border and the back kitchen yard gardens (Figure 4.14). The crops referred to here as snacks or minor crops include such examples as sugarcane, and Mundia whitey (*mkombero* in Luhyia language) which were normally not taken as part of the main meals.

Fruits were found on 11 out of the 15 view-walkshed sections and they were concentrated in the mid-farm (Back Kitchen yard) and the near house border sections of the SDU. The distribution of fruits in the different walkshed sections (Flat-40%, Slope-30%, and Valley-30%) showed no significant difference (Figure 4.15).

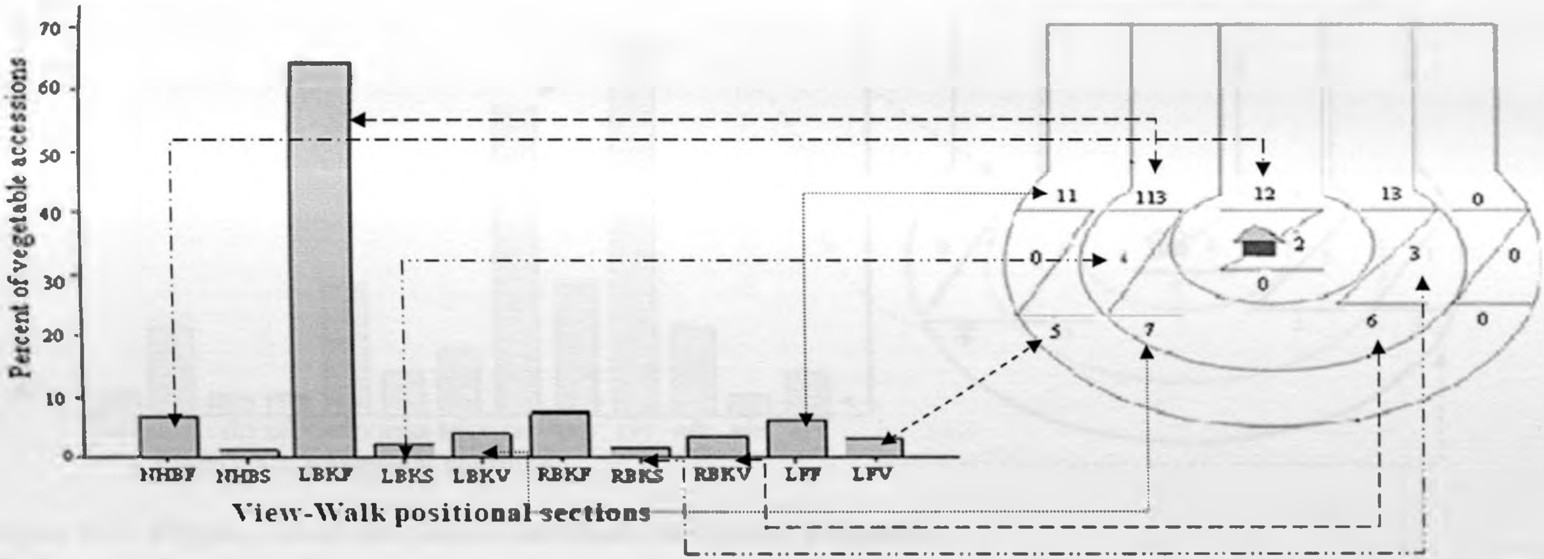


Figure 4.10: Mapping vegetable accession intensities as encountered in Esibuye and Vihiga farms (30 SDUs) across the left-right-centre positions of near-house, mid- and far-farm topo-sections

Legend: LBKF = Left back kitchen garden on flat ground; LBKS = Left back kitchen garden on sloping ground; LBKV = Left back kitchen garden on valley land; FF = Left far farm on flat ground; LFV = Left far farm on valley land; NHBF = Near house farm border on flat ground; NHBS = Near house farm border on sloping ground; RBKF = Right back kitchen garden on flat ground; RBKS = Right back kitchen garden on sloping ground; RBKV = Right back kitchen garden on valley land; 11= Number of vegetable accessions at respective view-walkshed sections of SDUs.

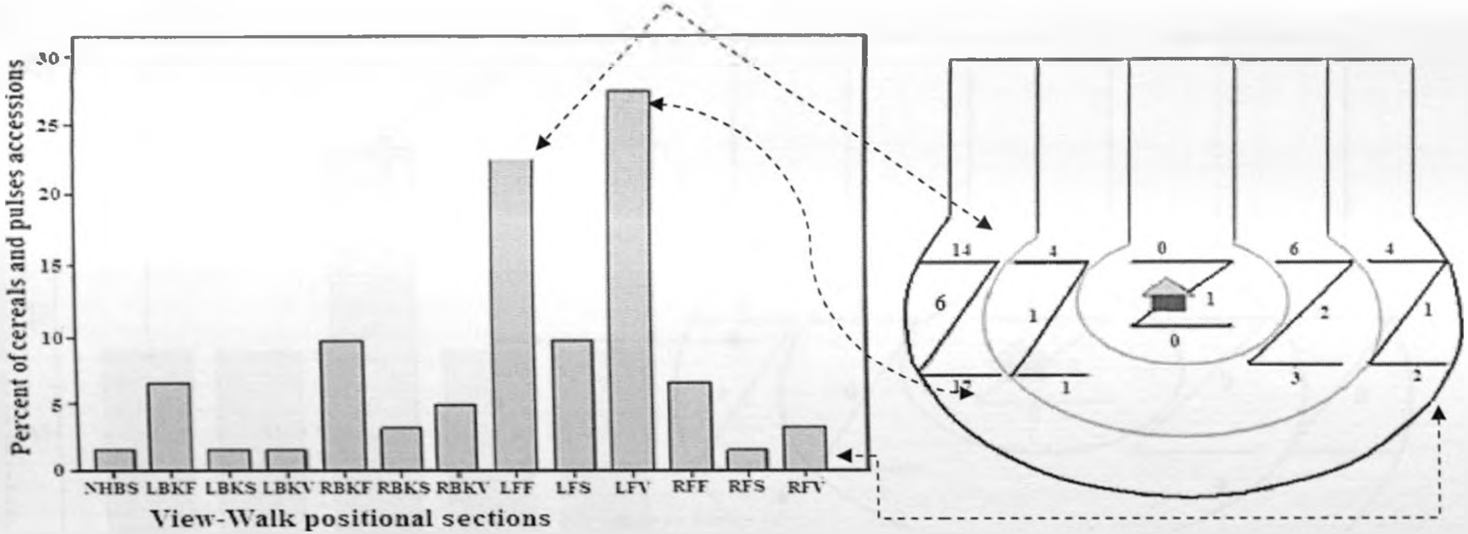


Figure 4.11: Mapping cereals and pulses intensities in Esibuye and Vihiga SDUs

Legend: LBKF = Left back kitchen garden on flat ground; LBKS = Left back kitchen garden on sloping ground; LBKV = Left back kitchen garden on valley land; LFF = Left far farm on flat ground; LFS = Left far farm on sloping ground; LFV = Left far farm on valley land ; NHBS = Near house farm border on sloping ground; RBKF = Right back kitchen garden on flat ground; RBKS = Right back kitchen garden on sloping ground; RBKV = Right back kitchen garden on valley land; RFF = Right far farm on flat ground; RFS = Right far farm on sloping ground; RFV = Right far farm on valley land; 14 = Number of cereals and pulses accessions at respective view-walkshed sections of SDUs.

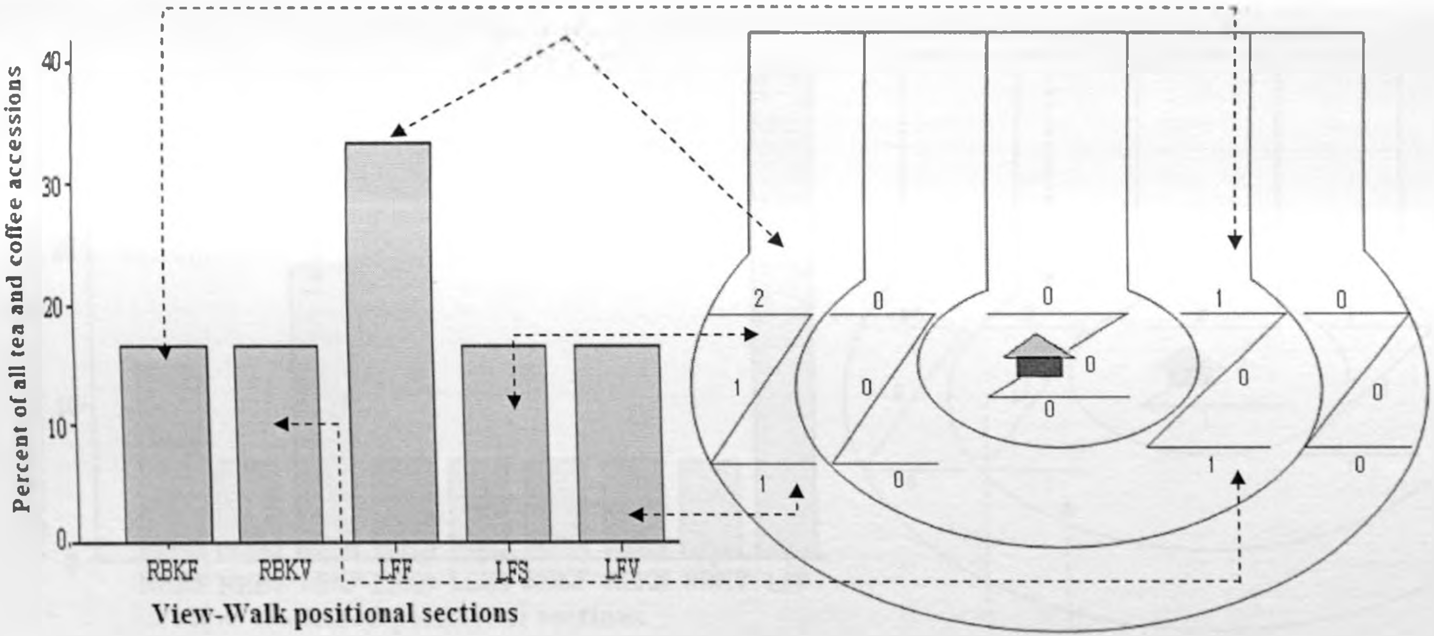


Figure 4.12: Mapping tea and coffee intensities in View-Walkshed sections of Esibuye and Vihiga SDUs.

***Legend*:** LFF = Left far farm on flat ground; LFS = Left far farm on sloping ground; LFV = Left far farm on valley land; RBKF = Right back kitchen garden on flat ground; RBKV = Right back kitchen garden on valley land; 2 = Number of tea and coffee accessions at respective view-walkshed sections of SDUs.

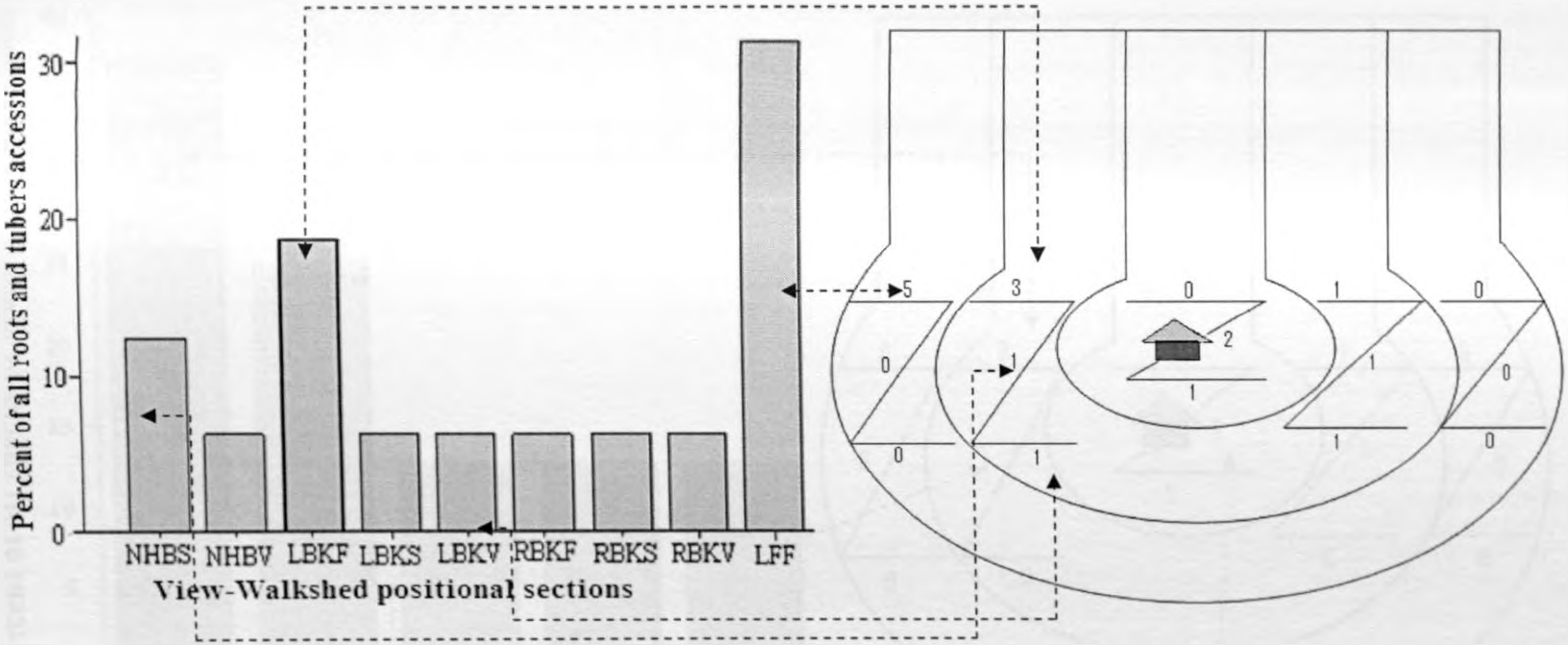


Figure 4.13: Mapping roots & tubers intensities in Esibuye and Vihiga SDUs

Legend: LBKF = Left back kitchen garden on flat ground; LBKS = Left back kitchen garden on sloping ground; LBKV = Left back kitchen garden on valley land; LFF = Left far farm on flat ground; NHBS = Near house farm border on sloping ground; NHBV = Near house farm border on valley land; RBKF = Right back kitchen garden on flat ground; RBKS = Right back kitchen garden on sloping ground; RBKV = Right back kitchen garden on valley land; 5 = Number of roots and tubers accessions at respective view-walkshed sections of SDUs.

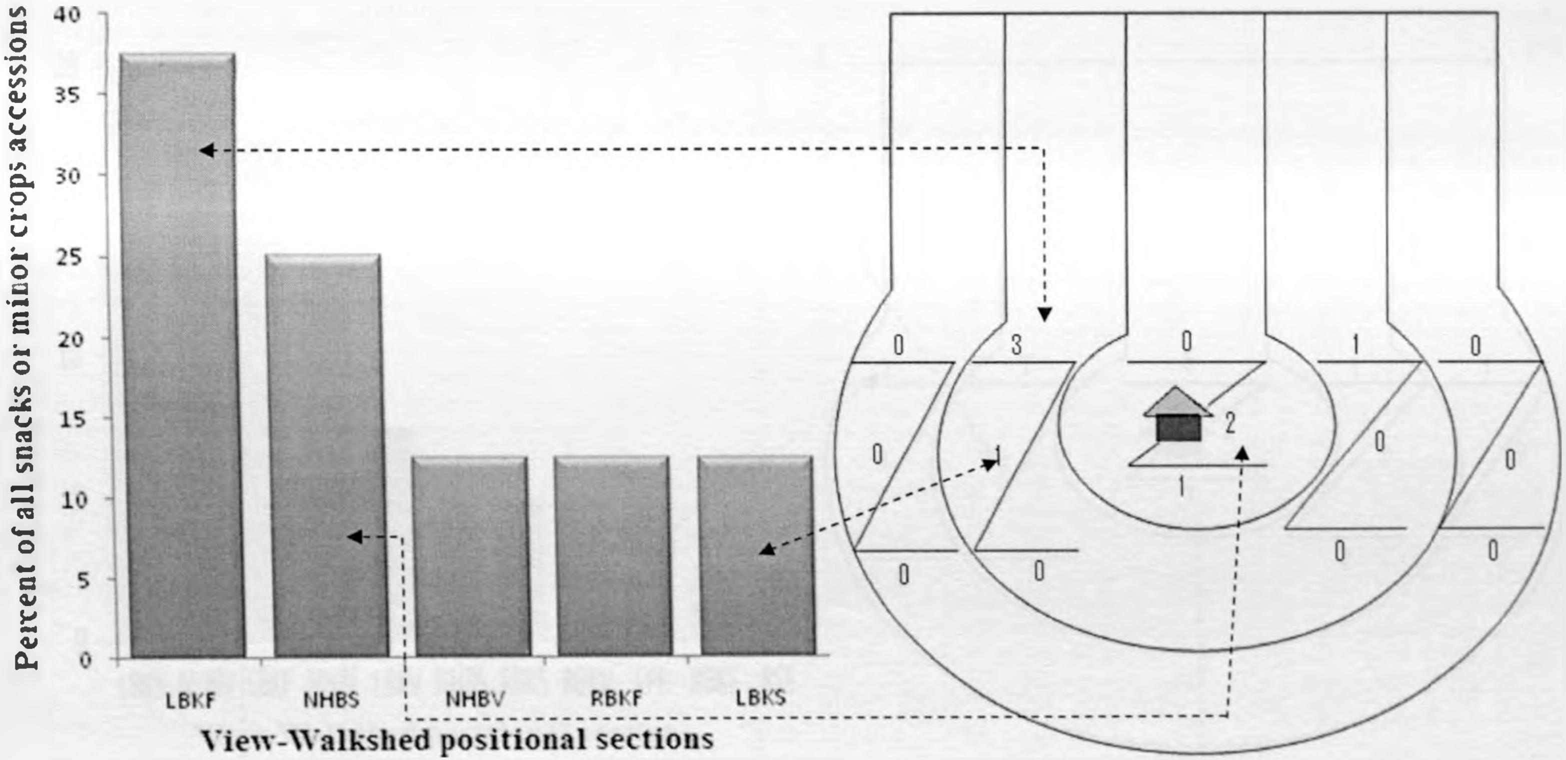


Figure 4.14: Mapping snacks or minor crops intensities **in Esibuye and Vihiga SDUs**

Legend: LBKF = Left back kitchen garden on flat ground; LBKS = Left back kitchen garden on sloping ground; NHBS = Near house farm border on sloping ground; NHBV = Near house farm border on valley land; RBKF = Right back kitchen garden on flat ground; 0 = Number of snacks or minor crops accessions at respective view-walkshed sections of SDUs.

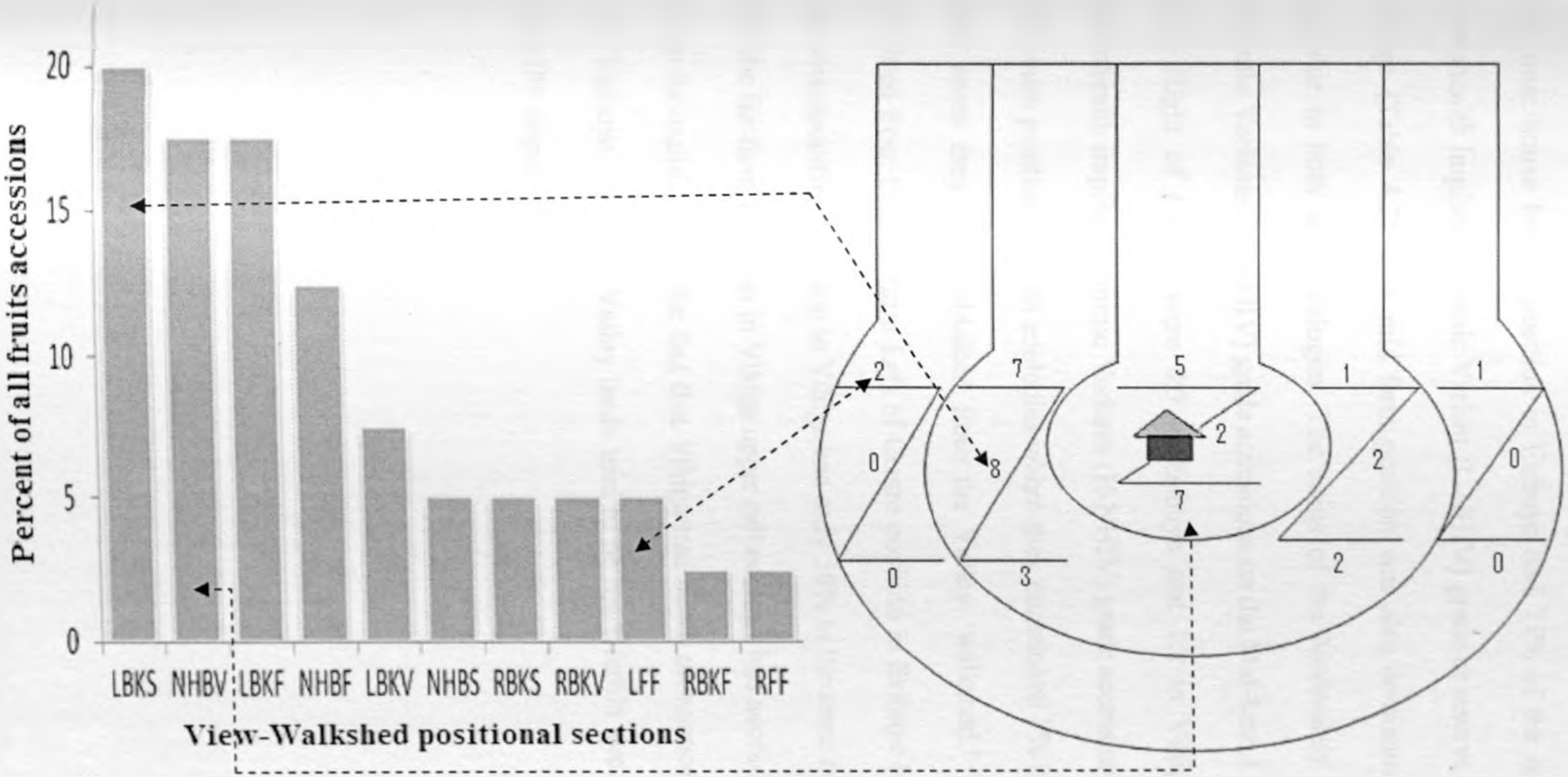


Figure 4.15: Mapping Fruits intensities **in Esibuye and Vihiga SDUs**

Legend: LBKF = Left back kitchen garden on flat ground; LBKS = Left back kitchen garden on sloping ground; LBKV = Left back kitchen garden on valley land; LFF = Left far farm on flat ground; NHBF = Near house farm border on flat ground; NHBS = Near house farm border on sloping ground; NHBV = Near house farm border on valley land; RBKF = Right back kitchen garden on flat ground; RBKS = Right back kitchen garden on sloping ground; RBKV = Right back kitchen garden on valley land; RFF = Right far farm on flat ground; 2 = Number of fruits accessions at respective view-walkshed sections of SDUs.

4.6.3.3 Mapping of NHIV grade variations among accessions as found on the SDU sections of Esibuye and Vihiga TAGEs.

The near house border position in Esibuye had 71% of the accessions in the less exceptional Nutrahealth implied Ionomic Variant (L-NHIV) grade or reserve corridor as compared to 100% in Vihiga (Table 4.2). The mid farm position was also dominated with accessions in the reserve corridor in both agro-ecologies. The ratios of the Moderately exceptional Nutrahealth implied Ionomic Variants (M-NHIV) grade accessions on the Mid-farm Left of Centre to those on the Mid-farm Right of Centre were 8:9 in Esibuye and 1:2 in Vihiga. All the Highly exceptional Nutrahealth implied Ionomic Variants (H-NHIV) grade accessions were found in the Far-farm Left of Centre position in both ecologies where they constituted 7% in Esibuye and 25% in Vihiga. In both cases they were obtained from the Valley 'walkshed.' Whereas 86% of the accessions obtained from the Far-farm Left of Centre position in Esibuye belonged to the L-NHIV corridor, the corresponding position in Vihiga had only 50% in the same corridor. These differences suggest that the far-farm position in Vihiga upper hill ecology had accessions with better NHIV grades and it can be explained by the fact that Vihiga had better pronounced valleys in the far-field position than Esibuye. Soils in Valley lands tend to be more fertile due to deposition of materials eroded from the slopes.

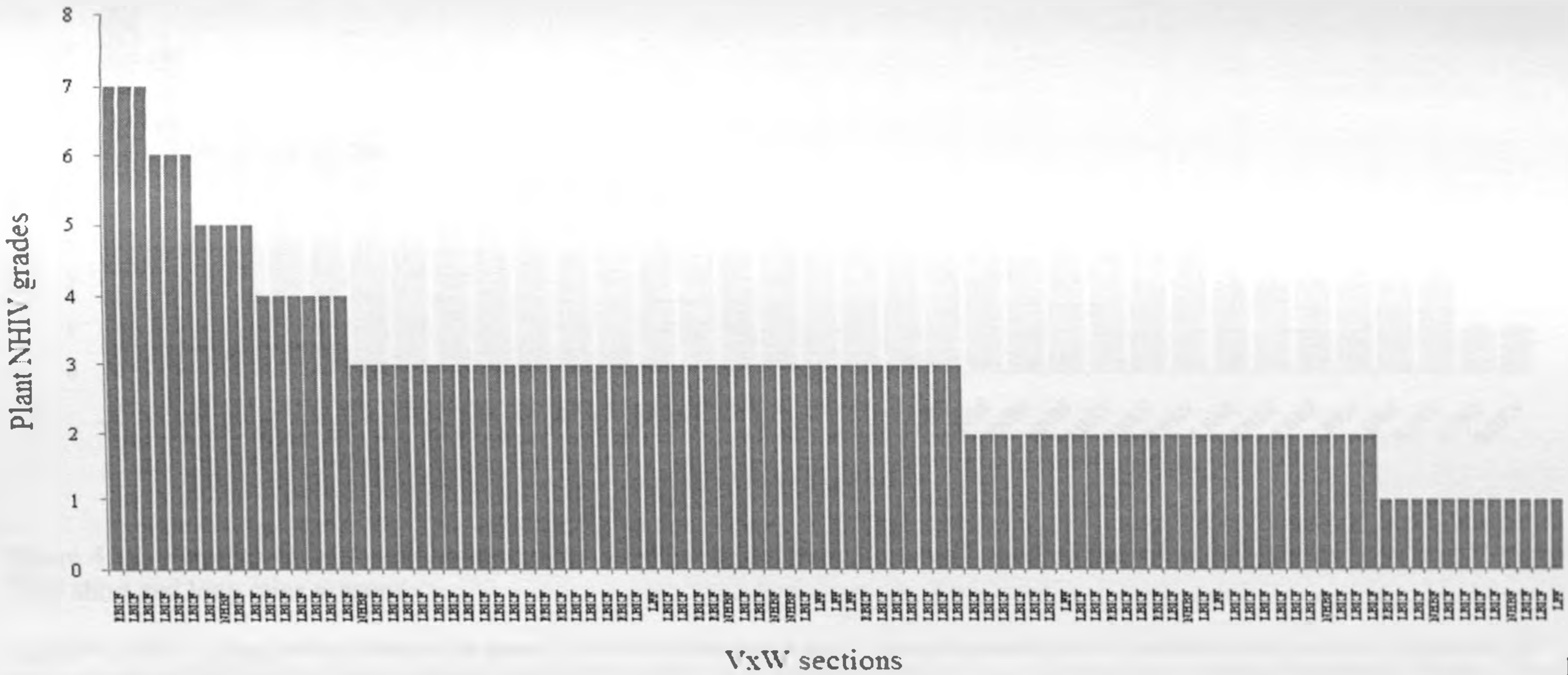
Table 4.2: Locationing (mapping) of NHIV grades on the View-walk sections of SDUs

	Agro-Ecology	Sectional grade within a grid			NHIV corridor composition (% per ecology)
Positional grids		Upper	Sloped	Valley	
Near House (Centre position)	Esibuye foothill	Amaranth: G3-P664; G3-P465; G5-P84; G5-P70; Cowpeas: G4-P100; Crotalaria: G4-P52; Jute plant: G2-P498; G3-P105; Local Kales: G5-P87; Pumpkin leaves: G5-P466; G3-P461; G2-P458; G2-P54; Spider plant: G4-P99; G3-P61; G3-P59	None	None	L-NHIV 71% M-NHIV 29% H-NHIV 0%
	Vihiga Upper hill	Amaranth: G4-P94; G5 -P74; G4 -P64; Cowpeas: G3-P43; G3-P49; Crotalaria: G4-P92; Solanum: G1-P516; G3-P93; Spider flower: G3-P96; G4-P40	None	None	L-NHIV 100% M-NHIV 0% H-NHIV 0%
Mid-farm Left of Centre	Esibuye foothill	Amaranth: G5-P450; G5 -P479; G2-P502; G3-P163; G2-P495; Beans: G3-P4; Cassava leaves: G3-P142; Cowpeas: G3-P463; G3-P494; G2-P456; G2-P497; Crotalaria:G3-P489; G2-449; Jute plant: G3-P496; G2-474; G2-P478; G1-P455; Kales: G5-P162; Pumpkin leaves: G4-P115; Local Kale: G2-P501; Pumpkin leaves: G7-P468; G6-P492; G5-P491; G4-P500; G3-P434; G3-P443; G3-P482; G3-P484; Solanum: G4-P568; G3-P566; G3-P486; G2-P558; G2-P499	None	None	L-NHIV 84% M-NHIV 16% H-NHIV 0%
	Vihiga Upper hill	Amaranth: G6-P424; G4-P560; G3-P405; G3-P503; G4-P388; G3-P564; G3-P409; G3-P411; G3-P567; G3-P423; G3-P571; G2-P529; Cowpeas: G3-P565; G2-531; G1-P518; G1-P556; G3-P134; Crotalaria: G1-P571; G1-P419; Jute plant: G2-P569; G1-P404; G1-P528; G2-P124; G4-P179; Pumpkin leaves: G7-P412; G4-P504; G3-P401; G3-P512; G3-P519; G2-P420; Solanum G6-P557; G3-P520; G2-P387; G2-P563; G2-P427; G2-P505; G5-P128; G2-P126; Spider flower: G3-P422; G2-P566	None	None	L-NHIV 90% M-NHIV 10% H-NHIV 0%

Mid-farm Right of Centre	Esibuye foothill	Cowpeas: G3-P 453; G3-P483; G4-P139; Maize: G5-P2	None	Crotalaria: G2-P136; G1-P159; Solanum: G2-P153; Amaranth: G5-P147	L-NHIV 82% M-NHIV 18% H-NHIV 0%
	Vihiga Upper hill	Amaranth: G7-P382; G3-P514; Jute plant: G3-P570; G1-P383; Pumpkin leaves: G2-P513	None	Cow peas: G3-P123 Spider flower: G2-P121	L-NHIV 80% M-NHIV 20% H-NHIV 0%
Far-farm Left of Centre	Esibuye foothill	Amaranth: G3-P567; Cassava leaves: G1-P568; Cowpeas: G3-P473 Crotalaria: G2-P472; Solanum: G3-P433	Crotalaria: G2-P68	Beans: G5-P116; G8-P5; G5-P3; G1-P8; G3-P10; Cowpeas: G4-P157; G4-P158; Maize:G1-P20;	L-NHIV 86% M-NHIV 7% H-NHIV 7%
	Vihiga Upper hill	Solanum: G2-P428; Spider flower: G8-P91; Beans: G1-P19	None	Pumpkin leaves: G7 -P118	L-NHIV 50% M-NHIV 25% H-NHIV 25%
Far-farm Right of Centre	Esibuye foothill	None	None	None	None
	Vihiga Upper hill	None	None	None	None

H-NHIV = Highly exceptional Nutrahealth-implied Ionomic Variants; M-NHIV = Moderately exceptional Nutrahealth-implied Ionomic Variants; L-NHIV = Less exceptional Nutrahealth-implied Ionomic Variants.

†*An alternative mapping arrangement is shown in Appendices 4.4 and 4.5.*



Figur
e 4.16: Nutrahealth implied Ionomic grades for plants at different View-walkshed positional sections in Esibuye and Vihiga during 2008 short rains season.

Legend: LBKF = Left back kitchen garden on flat ground; LBKS = Left back kitchen garden on sloping ground; LBKV = Left back kitchen garden on valley land; LFF = Left far farm on flat ground; LFS = Left far farm on sloping ground; LFV = Left far farm on valley land; NHBF = Near house farm border on flat ground; NHBS = Near house farm border on sloping ground; RBKF = Right back kitchen garden on flat ground; RBKS = Right back kitchen garden on sloping ground; RBKV = Right back kitchen garden on valley land.

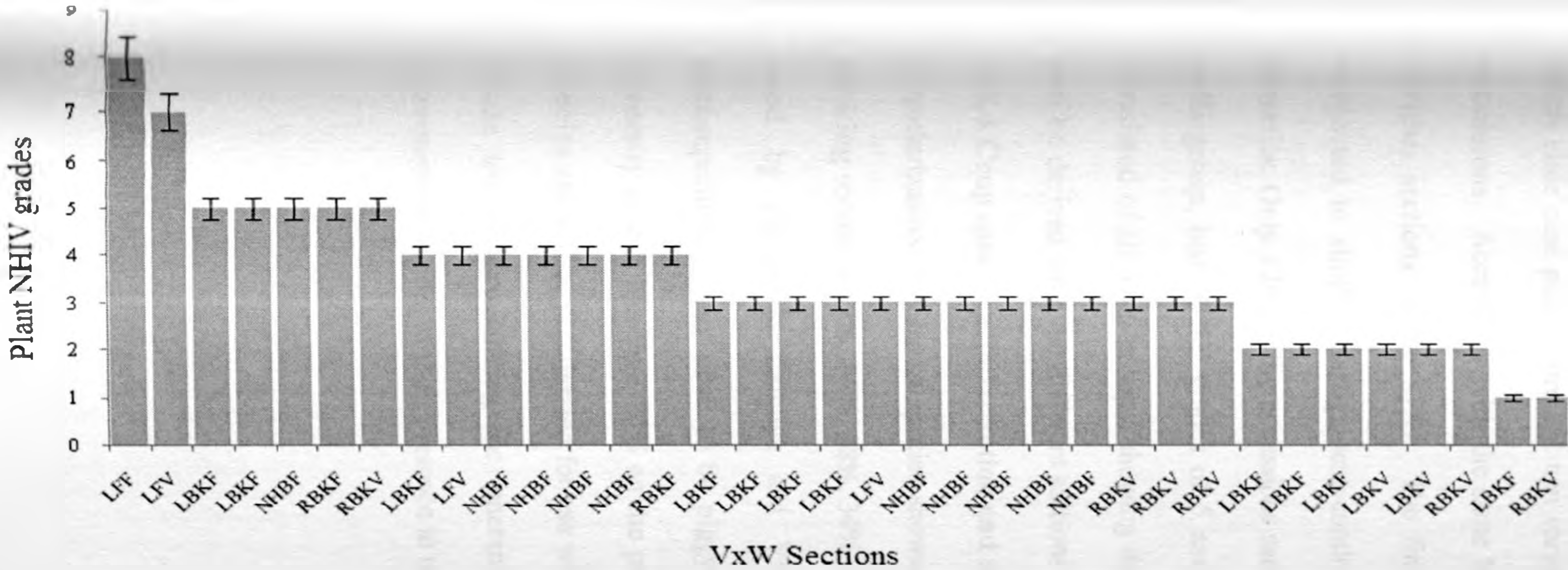


Figure 4.17: Nutrahealth implied Ionomic grades for plant at different View-walkshed positional sections in Esibuye and Vihiga during 2009 short and long rains seasons.

Legend: LBKF = Left back kitchen garden on flat ground; LBKS = Left back kitchen garden on sloping ground; LBKV = Left back kitchen garden on valley land; LFF = Left far farm on flat ground; LFS = Left far farm on sloping ground; LFV = Left far farm on valley land; NHBF = Near house farm border on flat ground; NHBS = Near house farm border on sloping ground; RBKF = Right back kitchen garden on flat ground; RBKS = Right back kitchen garden on sloping ground; RBKV = Right back kitchen garden on valley land.

Figures 4.16 and 4.17 above; show plant NHIV grade variation along the graphical staircase view. Each stair case plain represent non variation and the staircase climbs represent variation among accessions. Accessions with the same Nutrahealth implied Ionomic grades were obtained from various sections of the SDU. The finding gives an indication that different ionomes, when subjected to similar management conditions will give varying levels of Nutraceutical implied benefits. Only 12% of the accessions sampled in 2008 which were all belonging to the vegetable culti-group, had NHIV grades of 5 and above compared to 20% of the 2009 samples which consisted of six culti-groups, showing that increased diversity means an increase in benefits that can be derived from the different sections of the SDUs

4.6.4 Crop species popularization and utilization

Popularization ranking of species showed that maize, beans, kales, cowpeas, and bananas with ranking scores of 82%, 56%, 38%, 34% and 31%, respectively, were the most popular foods often used by people in Esibuye and Vihiga to which indigenous SHUB-Ionomic cropping accompaniments may need to be piggy-bagged with (Table 4.3). The rest of the agro-phyto-diversity scored less than 20% on the popularization scale. These results show that only a few species are to date popularized for use with a risk toward monoculture tendencies. Efforts must be made toward popularizing the inherent SHUB-Ionomic based diversity by highlighting and demonstrating more of their presence in the smallholdings.

Table 4.3: Food popularity ranking matrix (see appendix 4.2 for the ranking procedure*)

Crop food	Ranking score points	% score
1.Maize	247	82
2.Beans	167	56
3.Kales	115	38
4.Cow peas	102	34
5.Bananas	94	31
6.Amaranth	51	17
7.Jute plant	44	15
8.Pumpkin leaves	44	15
9.Sweet potatoes	38	13
10.Cassava	37	12
11.Spider flower	31	10
12.Solanum	29	10
13.Sorghum	21	7
14.Local kales	16	5
15.Pumpkins	15	5
16.Avocadoes	14	5
17.Napier grass	10	3
18.Crotalaria	9	3
19.Guavas	9	3
20.Dania	8	3
21.Ground nuts	8	3
22.Tea	7	2
23.Arrow roots	7	2
24.Finger millet	3	1
Standard Error	12.13136381	4.0359851
Relative Standard Error	25.85726	25.83030464

* Author's procedure

4.6.5 Women producers' perception of 'health' giving foods

Figure 4.18 shows the foods that were considered by the women operators of the SDUs to be important for the good health of the family members. The results indicate that according to the women operators of smallholder farm units in traditional agro-ecologies of Esibuye and Vihiga, maize, beans, vegetables, bananas and sweet potatoes in that order were the most important health giving foods. For 14% of the women, there was no distinction in terms of health giving value between different vegetable species. Three percent of them thought that indigenous vegetables had a unique health giving value whereas only 2% of them were aware that good health could only be achieved by eating different types of crop foods. They clearly need to be educated on the nutraceutical implied value of foods and healthy feeding habits that can alleviate the problem of hidden hunger. It is therefore imperative that a more scientific basis such as the nutra-ceutical rationale (i.e. the NHIV) can be demonstrated. It could have a high chance of sensitivity to the uptake of SHUB-Ionomic utilization and conservation focus.

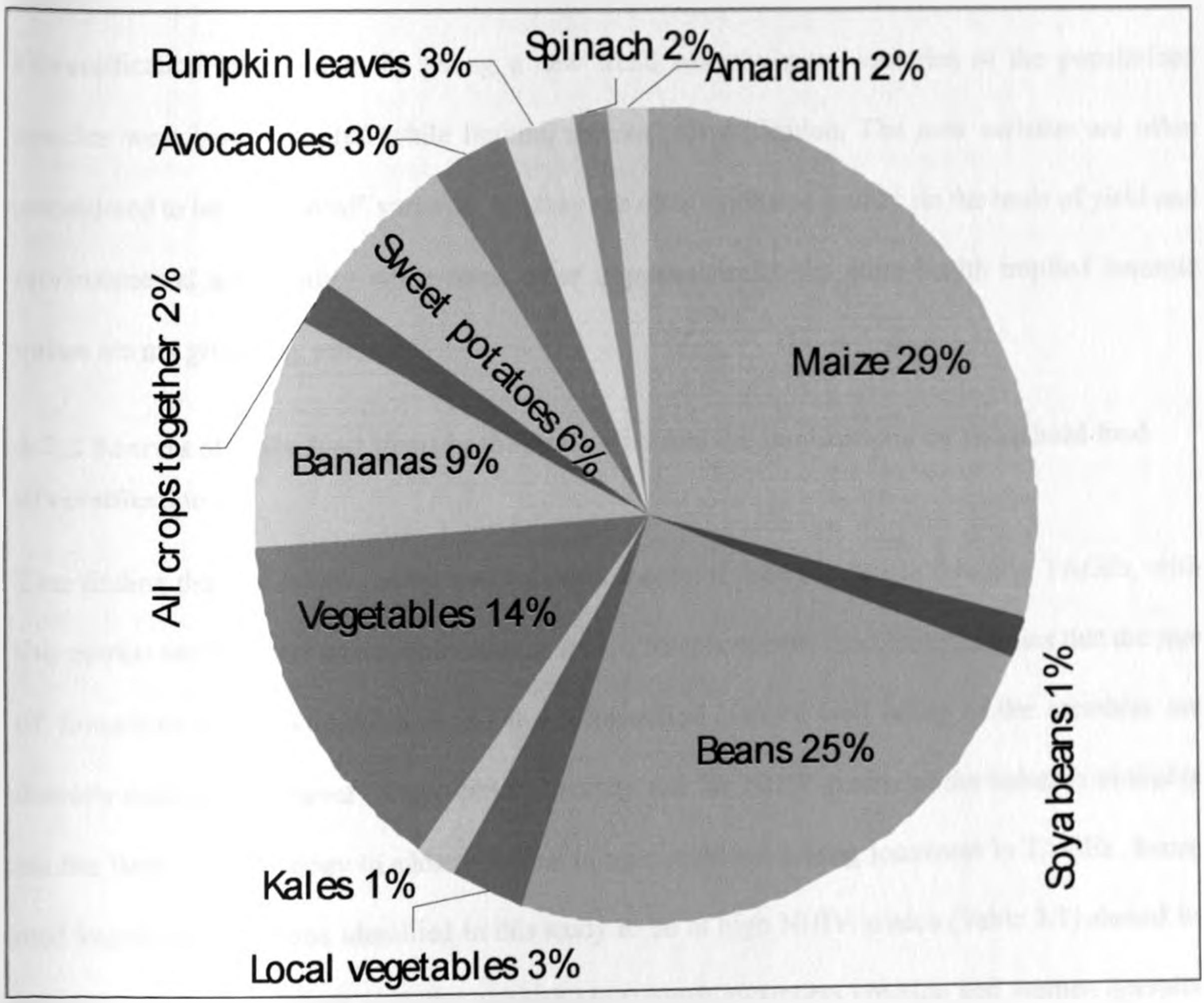


Figure 4.18: Foods considered by women operators as being important for good health without any prior nutraceutical guiding knowledge.

4.7: DISCUSSIONS

4.7.1 Crop diversification trends

Diversification appeared to be taking a new trend whereby new varieties of the popularized species were being adopted while limiting species' diversification. The new varieties are often considered to be 'improved' varieties, but they are often evaluated mainly on the basis of yield and environmental adaptability while some other important traits like nutra-health implied ionomic value are not given any attention.

4.7.2 Sources of main food items in the study sites and the implications on household food diversification

The finding that the home garden was the main source of food for people living in TAGEs, with the market serving only as a supplementary source for unavailable food items, implies that the rate of household food diversification and the nutraceutical implied well being of the members are directly related to the level of agro-phyto-diversity and the NHIV grades of the ionomes available on the farm. As a strategy to address hidden hunger problems among locavores in TAGEs , beans and vegetable accessions identified in this study to be of high NHIV grades (Table 3.1) should be promoted to increase their visibility and volume through awareness creation and women operator education.

4.7.3 The mapping findings

The top near house position was generally not used for cropping, but in rare occasions one finds fruit trees or vegetables. Generally this area was reserved for aesthetic or other cultural uses such as burial (Ritu, 2001). It was also used for livestock production activities as earlier indicated by Tittonell et al. (2005). Fruit trees were suitable for this area because of their multipurpose value properties as providers of ornamental value, nutrition value, and shade value. They were also used as tethers for livestock. Vegetables and bananas, on the other hand, required protection from theft and easy access from the house. Cereals, tea and coffee were generally not preferred near the house because they may harbour dangerous wild animals and they do don't need to be accessed easily from the kitchen sine they normally requie more elaborate processing before they can be cooked.

Roots, tubers and snacks were generally not grown in the far region of the farm, with exception of the top part which was generally preferred for agriculture. Such crops are not suitable on the erosion prone slopping area since it would lead to frequent loosening of the soil when harvesting is done. It is natural for the dwelling area to be located in less steep sections of the land and these happen to be the most suitable terrains for roots and tuber.

Mapping of nutra-health implied ionomic variants showed that whereas 86% of the accessions obtained from the Far-farm Left of Centre position in Esibuye belonged to the L-NHIV corridor, the corresponding position in Vihiga had only 50% in the same corridor. The converse was true in the near house border position where Esibuye had 71% of the accessions in the L-NHIV corridor as compared to 100% in Vihiga. These differences suggest that the far-farm position in Vihiga upper hill ecology had accessions with better NHIV grades compared to the corresponding viewshed position in Esibuye and it can be explained by the fact that Vihiga had more pronounced valleys in the far-field position than Esibuye. Soils in Valley lands tend to be more fertile due to deposition of materials eroded from the slopes. Esibuye on the other hand had more gentle slopes allowing for more uniform utilization of the SDU sections. It further explains why the near house positions in Esibuye had a higher percentage of the accessions near house in the M-NHIV corridor than Vihiga.

All the Exceptional Nutrahealth implied Ionomic Variants (E-NHIV) were found in the Far-farm Left of Centre position in both ecologies where they constituted 7% in Esibuye and 25% in Vihiga. In both cases they were obtained from the Valley 'walkshed.' When foods that have better NHIV grades are grown far from the house, it means that they are less popular and their rate of use is also low, therefore household members cannot derive maximum benefit from them.

The finding that accessions with the same NHIV grades were obtained from various sections of the SDU can be explained by the variability in the genotype-environment interactions of various ionomes and gives an indication that different ionomes, when subjected to similar management conditions will give varying levels of Nutraceutical implied benefits.

4.7.4 The effects of species popularization on crop species diversification, utilization and the nutraceutical implied food security in TAGEs

Popularization and de-popularization trends showed that traditional foods like finger millet, arrow roots, sorghum and many indigenous leafy vegetables were being replaced by exotic crop species like maize, beans and kales. This trend can be attributed to the commercial nature of the new species, a status which they have acquired through promotion over the years. Popularization was also found to be related to perception of certain foods as health giving. Cereals and pulses are the main staple foods in Kenya and subsistence farmers perceive them as food security crops (Ariga et al. 2010). They were also considered by the SDU operators to be important foods for good health. It was however found that this perception was wrong since most of the popularized species had no accessions in the high NHIV grades corridor. A wide variety of indigenous foods have been de-popularized through neglect and lack of attention to the extent of being viewed as weeds or wild foods. This has resulted into reduction in agro-phyto-diversity with its consequences of declined diet variability, reduced NHIV value obtained from plant foods, and hence prevalence of hidden hunger related problems. It has been shown that the leafy tissues of vegetables especially the indigenous types which were being depopularized contain relatively higher amounts of nutrients than seed material of cereals and fleshy parts of the fruits (Munene, 2004). In fact over reliance on maize as the main staple food in Kenya has also been blamed for persistent food insecurity due to its vulnerability to adverse weather conditions that have become common (Otunge et al. 2010). The NHIV value of more popular species can be improved through breeding. Better still, availing the correct information on the implied health giving value to the operators of SDUs can help them to make appropriate decisions regarding agro-phyto-diversity and diet variation.

4.7.5. The management of SHUBI-Ionomic Diversity Unit (SDU)

Apart from tenure status and regulations, land access rights and size, decisions on land use management and its conservation greatly depend on its morphology including geometrical shape, topography, and location in relation to public infrastructure which dictate where the house is sited and how the rest of the land is used. Convenience of access and security of the crops against theft were identified as the most important considerations in 'allocationing' of crops on the viewshed SDU sections. Crop types found near the farm-house were the most popularized and used ones like bananas and kales. The popular crop species grown closer to the farm-house should therefore have superior nutaceutical implied value as a strategy of addressing problems of hidden hunger. Such an objective can only be achieved through awareness creation to farm operators, researchers and agricultural extension agents.

4.8 Conclusions and recommendations

Decisions about allocation of agro-phyto-diversity positions on smallholder SDUs take into consideration a number of factors. The site distance from the house and slope of the land are two important factors that determine where SDU operators allocate plant accessions on their land. These decisions affect the realization of the mineral micronutrient ionomic potential of plant accessions and the nutra-health implied ionomic value that people derive from consuming the food plants that are grown on specific sections of the SDUs. Topo-positional mapping of nutraceutical-implied mineral agro-phyto-diversity in Esibuye and Vihiga revealed that the more intensively used SDU sections which are more gently sloping and are easily accessible from the farm house had accessions of the most popularized plant species. Most of them were however in the L-NHIV grade corridor, but erroneously considered as the best foods that provide good health.

The un-popularization of indigenous plant foods should be addressed by all stakeholders using various means including research, information communication and management, establishment of village seed banks and equipping them with adequate facilities and information on the attributes of varieties banked. The wrong perception of health giving foods is a demonstration of lack of awareness that needs to be addressed using collaborative efforts that should target especially the youth and women. So even as efforts shift towards promoting farm business, agro-phyto-diversity conservation, as well as the associated health and nutrition messages should not be relegated too much in favour of commercial and profitability messages. Such knowledge will also influence the management of the SDUs and improve the NHIV grades of foods produced therein. It is, therefore, recommended that perceptions should be further enlightened by factual evidence from research which should be clearly communicated to the farmers.

CHAPTER FIVE

General Discussion, Conclusions and Recommendations

5.1 General discussion

The agro-phyto-diversity in smallholder traditional agro-ecologies of Esibuye and Vihiga was found to be declining. This trend has been observed in smallholder farms elsewhere in Africa and Asia (Mitra and Pathak, 2008; Vorster et al. 2008; and Abukutsa-Onyango, 2008). This study went further and identified the disappearing species from the smallholder traditional agro-ecologies of the Lake Victoria Basin as well as those that have persisted and the newly introduced ones. These changes in agro-phyto-diversity in TAGEs can be attributed to management decisions that operators make in the face of the changed circumstances of reducing sizes of land holdings and increased promotion of exotic and commercial species. The selective promotion in terms of research and development attention has also resulted into a shift in food popularization and utilization rates, but has negatively impacted on diet diversification and the nutraceutical implied value of food to the household members. The most popularized and utilized foods such as maize, beans and kales were found to predominate in the TAGEs. An earlier study had reported similar findings in Kiambu and Vihiga district of Kenya (Salasya, 2005). However, the popularized species were found to be of lower NHIV grades compared to some of the less popularized ones such as amaranth, pumpkin leaves, solanum, local kales, and spider flower. This popularization of staple foods with low NHIV grades explains why hidden hunger may still be a problem in the region in keeping with the earlier reports regarding the relationship between diet diversification and availability as well as accessibility of diverse food types (Munene, 2004; Mitra and Pathak, 2008; and Oguntona et al. 1987). Promotion of accessions which were identified to be of high

NHIV grades can be recommended as a strategy of improving the health of the people living in TAGEs and depend mainly on locally produced foods. Farmers should therefore be made aware of the fact that certain crop foods which have been lowly regarded (less popular) can provide better nutraceutical implied benefits than some of their preferred staples through promotional activities. Such lobbying will ensure that production of the most nutraceutically valuable accessions are increased to help solve the problems associated with hidden hunger. Three amaranth accessions (S09F30VNU P74, S09F38ENU P70 & S09F40ENU P84) and one local kale accession (S09F33ENU P87) found to be nutraceutically superior are potential candidates for such promotional activities. The fact that most of the nutraceutically superior accessions were found close to the house (in the mid farm section) is good news because it has been shown that this section of the SDU normally contains the most popular and frequently used foods. However, hidden hunger may still be a problem in the region because the majority of the locally produced foods belong to the 'reserve' corridor (i.e. they are of low NHIV grade). Only 10% and 22% of the locally produced foods in 2008 and 2009, respectively, had medium to high NHIV grades.

The complexity of interactions of factors that affect plant nutrition can explain the observation that the concentration of elements in plant tissues was not significantly related to that in the respective soils. Barber (1995), Brady and Well (2002) and Wamala (2007), have described how biological, physical, and chemical processes and interactions among many different components of the soil and the environment such as minerals, air, water, organic matter and the plants inherent characteristics affect the realization of the optimum genetic potentials of any accession. So the management interventions by farm operators to ensure the optimum conditions required for any superior plant accession prevails is crucial. The attainment of the optimum potentials of the identified nutraceutically superior ionomes can be enhanced through appropriate land husbandry practices that include slope management, soil and water conservation and management, addition of soil amendments and plant nutrients, agro-biodiversity control, and species' 'allocationing' on the farm.

5.2 General conclusions

- Tastes and preferences in TAGEs are changing and traditional and/or indigenous foods are being dropped in favour of exotic and commercial species and varieties. This study has also shown that most of the preferred and frequently utilized foods in the study area had less nutraceutical value compared to some of the less preferred ones. These changes have implications in the nutraceutical wellbeing of the household members.

- The study identified twenty three accessions as belonging to the 'core' collection corridors with NHIV grades of five or more. Eight of the high ranking accessions were from Vihiga and included three amaranth accessions (S08F1VIkbNUP382, S08F8VEmdNUP424, and S09F30VNU P74); two pumpkin leaves accessions (S08F7VEmdNUP412, and L09F1VNU P118); two solanum accessions (S08F3VIkbNUP557, and L09F7VNU P128) and one spider plant accession (S09F1VNU P91). The remaining 15 high ranking accessions were found in Esibuye and comprised of five amaranth accessions (S08F13EEbsNUP450, S08F20EEbyNUP479, S09F40ENU P84, S09F38ENU P70, and L09F13ENU P147); four pumpkin leave accessions (S08F17EEbyNUP468, S08F24EEbsNUP492, S08F16EEbyNUP466, and S08F23EEbyNUP491); three beans accessions (L09F15ENU P5, L09F15ENU P3 and L09F14ENU P116); one kale (L09F22ENU P162); one local kale (S09F33ENU P87) and one maize (L09F26ENU P2). Three amaranth accessions (S09F30VNU P74, S09F38ENU P70 & S09F40ENU P84) and one local kale accession

(S09F33ENU P87) were singled out for having been graded high in a previous study by Akundabweni et al. (2006).

- 'Allocationing' and 'locationing' farm decisions in SDUs are influenced by four main factors namely: The site location relative to the farm-house (Viewshed); the topography of the land (walkshed); the food preference or popularization and the need for security both for the crop and the household members.

- The allocationing and locationing decisions made by women SDU operators affect the realization of the mineral micronutrient ionomic potential of plant accessions and the nutrahealth implied ionomic value that people derive from consuming the food plants that are grown on specific sections on the SDUs. These decisions therefore have implications on the nutraceutical wellbeing of the household members.

5.3 General recommendations

- The disappearance of indigenous plant foods should be addressed by all stakeholders using various means including research, information communication and management, establishment of village seed banks and equipping them with adequate facilities and information on the attributes of varieties banked.

- It is further recommend that the 'core' corridor accessions and especially the three amaranth accessions and one local kale accession singled out in two studies should be given further research and development attention by national and international research institutions so that they can be developed and promoted as nutraceutically superior accessions suitable for use as tools for addressing hidden hunger problems.

- As another strategy in tackling the problem of hidden hunger, it is recommended that the species of crops that are preferred and used more often as food should be targeted for improvement in their nutrahealth implied ionomic value, and the less preferred high value species for promotional activities to increase their visibility and volume. The selling point for such promotional activities should emphasize on the findings on nutraceutical implied value of accessions.

General References

Abukutsa-Onyango, M. O. 2008. The Role of Universities in Promoting Underutilized Crops: The Case of Maseno University, Kenya. Acta Horticulturae 806: 155 – 162.

Akundabweni L. S. M (unpublished). XRF/NIRS Determinations for Mapping Practices and Processes Affecting Agro biodiversity In Smallhold Agroecosytems (TAGEs).

Akundabweni L.S.M., Maina D.M., and Mulokozi G. (Unpublished). Characterization of African leafy vegetables for organo- and mineral micronutrient densities based on X-ray fluorescence and high performance liquid chromatography.

Akundabweni L.S.M., Namutebi A., Kimwiye J., and Rweyenamu L. 2008. X-Ray Fluorescence Detected Variation In Nutraceutic Implied Mineral Density In Underutilized Plants Mapped as Women Operated Smallholder Units in the Lake Victoria Basin. Acta Horticulturae 806: 257 – 268.

Akundabweni, L.S.M, Namutebi, A, Kimiywe, J.O., 2010. Linking Nutraceutical-Based Cropping and Dietary Agrobiodiversity to Land Use in Lake Victoria Basin on Women-Operated Smallholdings. Project report to VicRes.

Antonio C. Allem., 2001. Managing gene banks: Seed base collection examined. Genetic resources and crop evolution 48 (4): 321-328. Kluwer Academic Publishers, Netherlands.

Ariga Joshua, Jayne, T.S., and Njukia Stephen, 2010. Staple food prices in Kenya. Paper prepared for the COMESA policy seminar on "Variation in staple food prices: Causes, consequence, and policy options", Maputo, Mozambique, 25-26 January 2010 under the Comesa-MSU-IFPRI African Agricultural Marketing Project (AAMP)

Attere, 1990. Conservation and Use of Indigenous Vegetable Resources in the SADCC Region. In Opeña, R.T and Kyomo, M.L. (eds.) Vegetable Research and Development in SADCC Countries: proceedings of a workshop held at Arusha, Tanzania, 9-13 July 1990. Asian Vegetable Research and Development Centre. AVRDC 90; 55-61.

Barber, S. A. 1995. Soil nutrient bioavailability, John Wiley & son Inc. New York.

Bashaasha B., Kidoido M. and Friis EH., 2006. Determinants of wellbeing among smallholders in Adjumani District, Uganda: Poster paper prepared for presentation at the International Association of Agricultural Economists Conference, Gold Coast, Australia, and August 12-18, 2006. Available at http://ageconsearch.umn.edu/bitstream/pdf

Baxter I., Hosmani P S., Rus A, Lahner B., Borevitz JO, et al. (2009). Root Suberin Forms an Extracellular Barrier That Affects Water Relations and Mineral Nutrition in Arabidopsis. PLoS Genet 5(5): e1000492. doi:10.1371/journal.pgen.1000492.

Brady, N. C., and Well R. R., 2002. The Nature and properties of Soils. Pearson Education inc. Upper Saddle River, New Jersey.

Christian J., Nelson, L., Arthur J., Jennifer L., and Gary. W. 2008. Mapping potential foodsheds in New York State: A spatial model for evaluating the capacity to localize food production; Renewable Agriculture and Food Systems: 24(1); 72–84.

Christian J., Nelson, L., Jennifer L., and Gary. W. 2008 Foodshed analysis and its relevance to sustainability: renewable Agriculture and Food Systems: 24(1); 1-7.

Deadman, P. 2005. Household Decision Making and Patterns of Land Use Change in LUCITA: An Agent Based Simulation of the Altamira Region, Brazil. In Zerger, A. and Argent, R.M. (eds.) MODSIM 2005. International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2005, pp. 120-126. ISBN: Available at website: http://www.mssanz.org.au/modsim05/papers/ascough_1.pdf. (Visited September 12, 2010).

Fiona Watson, 1998. Micronutrients - The Basics. Draft guideline material Issue 5 (page 26) Institute of Child health, London. Available at website: ttp://fex.ennonline.net/5/contents.aspx. (Verified September 26, 2010).

Food and Agricultural Organization of the United Nations. 1995. Farm household decision making and extension framework for understanding farm household-level decision making and design of agro forestry extension strategies. Available at website: http://www.fao.org/docrep/x0266e/x0266e00.htm (Accessed September 10, 2010).

Food and Agriculture Organization of the United Nations. 2008. Climate Change and Food Security: A framework document. Available at website: http://www.fao.org/docrep/010/k2595e/k2595e00.htm (Verified September 25, 2010).

Frankel, O.H. 1984. Genetic perspectives of germplasm conservation. In W.K. Arber, K. Llimensee, W.J. Peacock and P. Starlinger (eds.). Genetic Manipulation: Impact on Man and Society, Pp. 161-170. Cambridge University Press, Cambridge, UK. Available at http://books.google.co.ke/books. (Verified on 28/2/2011)

Gautam, R., Suwal, R. and Sthapit, B.R. 2009. Securing Family Nutrition Through Promotion of Home Gardens: Underutilized Production Systems In Nepal. Acta Hort. (ISHS) 806:99-106. Available at http://www.actahort.org/books/806/806_10.htm

Grusak Michael A. 2002. Enhancing Mineral Content in Plant Food Products. Journal of the American College of Nutrition. 21(90003): 178S-183S. Published by the American College of Nutrition. Available at http://www.jacn.org/cgi/content/abstract/21/suppl_3/178S (Accessed 9 September 2010).

Hughes, J. 2008. Just Famine Foods? What Contributions Can Underutilized Plants Make To Food Security? Acta Horticulturae 806: 39 – 48.

Keith D. Shepherd and Markus G. Walsh, 2007. Infrared spectroscopy-enabling an evidence-based diagnostic surveillance approach to agricultural and environmental management in developing countries. J. Near Infrared Spectroscope. 15, 1-19.

Kimiywe Judith, 2009. Indigenous Vegetable Recipes: Energy & Micro-nutrient Values. Point one Media, Nairobi

Kristof, 2009. The Hidden Hunger. The New York Times, 23rd May 2009. Available from http://www.nytimes.com/2009/05/24/opinion/24kristof.html

Thiam I., Samba K., and Lwanga D., 2006. Diet related Chronic Diseases in West Africa Region. In Kaia Engesveen, 2006. Diet-related Chronic Diseases and the Double Burden of Malnutrition in West Africa. SCN news 33(6). Available from www.unscn.orgscnnews33.pdf

Kumaresan A., Bujarbaruah K. M., Pathak K. A., and Brajendra T. R., 2009. Soil–plant–animal continuum in relation to macro and micro mineral status of dairy cattle in subtropical hill agro ecosystem. Tropical Animal Health and Production 42 (4) 569-577

Lahner B, Gong J, Mahmoudian M, Smith EL, Abid KB, Rogers EE, Guerinot ML, Harper JF, Ward JM, McIntyre L, Schroeder JI, Salt DE (2003). Genomic scale profiling of nutrient and trace elements in *Arabidopsis thaliana*. Nat Biotechnol 21: 1215-1221.

Mepba H. D, Eboh I., and Banigo E. B., 2007 Effects of processing treatments on the nutritive composition and consumer acceptance of some Nigerian edible leafy vegetables. AJFAND 2007; 7(1): 1-18.

Michael J. Vanni, William H. Renwick, Jenifer L. Headworth, Jeffery D. Auch and Maynard H. Schaus, 2001. Dissolved and particulate nutrient flux from three adjacent agricultural watersheds: A five-year study. Biogeochemistry 54 (1) 85-114. Kluwer academic publishers. Netherlands

Mitra, S.K. and Pathak, P.K. 2008. Underutilized Plant Species: Implications in Homestead Farming. Acta Horticulturae 806: 107 – 114.

Mnzava N.A., 1995. Vegetable crop diversification and the place of traditional species in the tropics Traditional African Vegetables. Proceedings of the IPGRI International Workshop on Genetic Resources of Traditional Vegetables in Africa: Conservation and Use 29-31 August 1995, ICRAF-HQ, Nairobi, Kenya.

Msuya, J.M., Mamiro, P. and Weinberger, K. 2009. Iron, zinc and β-carotene nutrient potential of non-cultivated indigenous vegetables in Tanzania. Acta Hort. (ISHS) 806: 217-222.

Munene R. W., 2004. Inter-specific variation in trace element micronutrient and macro element density by use of energy dispersive x-ray fluorescence (EDXRF) in selected indigenous food plants. Master of Science thesis, University of Nairobi.

Ndufa J. K., Cadisch G., Poulton C., Noordin Vanlauwe Q. and B., 2005. Integrated Soil Fertility Management and Poverty Traps in Western Kenya., Available at website: http://www.research4development.info/PDF/Outputs/NatResSys/R7962Pap1.pdf. (Accessed September 9, 2010).

Ninez, V. 1987. Household gardens and small scale food production. Food and Nutrition Bulletin, 7(3). Available at: http://unu.edu/unupress/food/8F073e/8F073E01.htm. (verified November 5th 2010)

Oguntona C. R. B., Williams L. S., and Biu A. K., 1987. The food and nutrient intake of adolescents in Borno, Nigeria. Nutrition Reports international 36 (5)981-987.

Otunge Daniel, Muchiri Nancy and Wachoro Grace, 2010. Reducing maize insecurity in Kenya: the WEMA project. A policy brief produced by the African Agricultural Technology Foundation (AATF).

Peter M. Bierman and Carl J. Rosen, 1999. Nutrient Cycling & Maintaining Soil Fertility in Fruit and Vegetable Crop Systems. Ohio State University Piketon Research & Extension Center (SWR-2, 1999).

Ritu Verma, 2001. Gender, Land, and Livelihoods in East Africa: Through Farmers Eyes. International Development Research Centre, Ottawa, Canada. Available at: http//publicwebsite.idrc.ca

Rus A., Baxter I., Muthukumar B., Gustin J., Lahner B, Yakubova E., and. Salt D., 2006. Natural variants of AtHKT1 enhance Naþ accumulation in two wild populations of Arabidopsis. PLoS Genet 2(12): e210. doi:10.1371/journal.pgen.0020210. 1964-1973

Salasya, B. D. S., 2005. Crop production and soil nutrient management: An economic analysis of households in Western and Central Kenya. PhD. Thesis. Wageningen University.

Salt DE, Baxter I, Lahner B, 2008. Ionomics and the study of the plant ionome. Annual Review of Plant Biology 59: 709-733. Available at http://www.annualreviews.org/ /annurev.arplant.59.032607.092942

The World Bank group, 2008. The end of year review 2008. Available at website: http://www.worldbank.org /endofyear /2008/endofyear-08.htm.

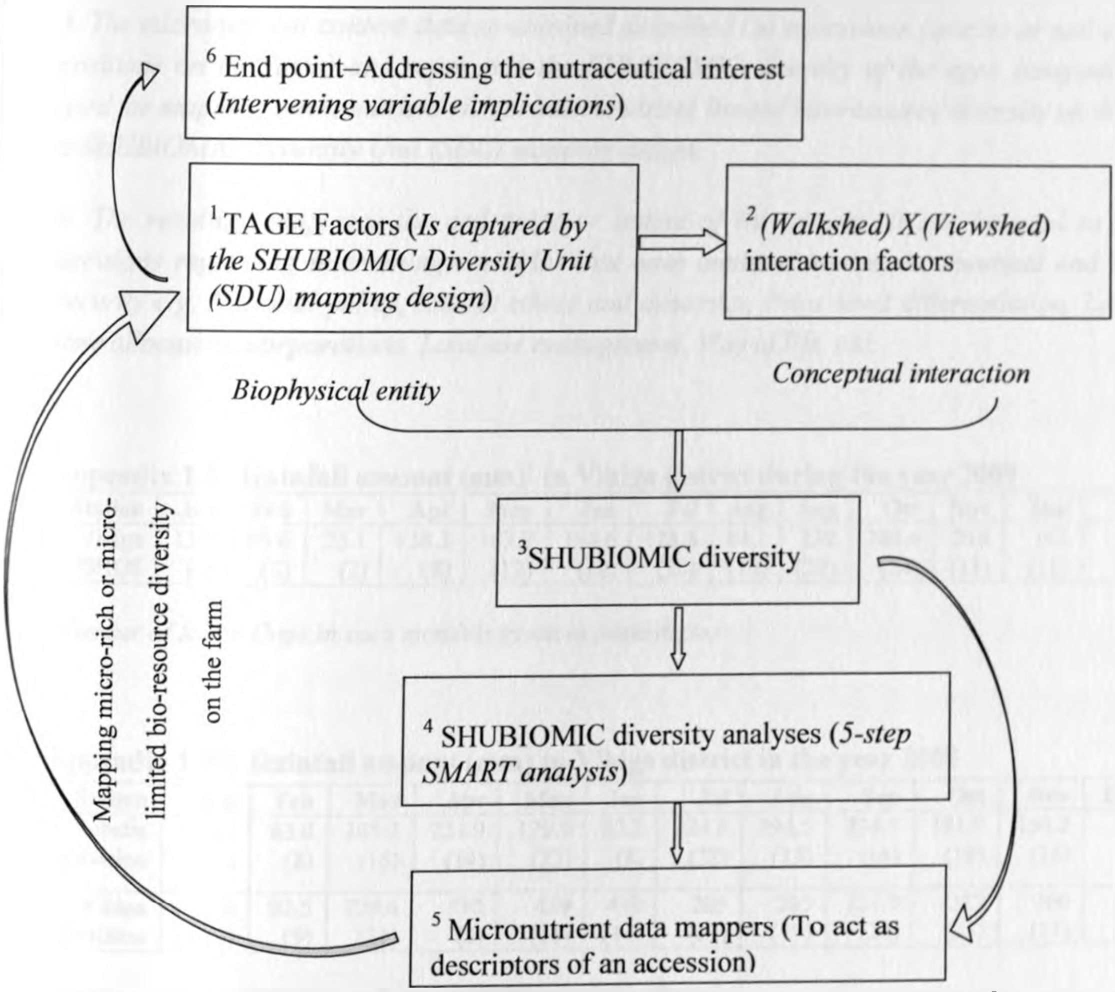
UNESCO, 2008. Indigenous Food Plants Programme: using locally available edible species to enhance community health provide income and conserve biodiversity. Available at website: http://www.unesco.org/shs/most.

Vorster, H.J., Van Rensburg, W.S, Stevens, JB., and Steyn, G.J. 2008. The Role of Traditional Leafy Vegetables in the Food Security of Rural Households in South Africa. Acta Horticulturae 806: 223 – 228.

Wright Alan L., Hanlon Edward A., Sui David, and Ronald Rice, 2009. Soil pH Effects on Nutrient Availability in the Everglades Agricultural Area

Appendices

Appendix 1.1: Conceptual model of the small-holder utility-based bio resource micronutrient diversity mapping project.



1. The traditional agro-ecosystem (TAGE) is a biophysical entity with inherent factors such as Land size, Topography, Proximity to the house, Cultural uses, cultural practices, Soil PH, Soil nutrient content, and Soil type which make up the environment in which a crop species interacts to express its nutraceutical potential.

2 & 3. These factors and their interaction influence the Small Holder Utility-based Bio-resource Micronutrient (SHUBIOMIC) diversity on the farm including livestock diversity, crop diversity and soil diversity

4. The diversity was analyzed in five steps involving Scripting in the field to identify species and soil samples with accession numbers, Mark mining in the lab using XRF to ascertain the non aggregated nutrient density of each accession, Aggregating the nutrient densities, Rating the accessions and Targeting the top grades for further analysis and promotion (i.e. 5-step SMART analysis)

5. The micronutrient content data so obtained described the accessions (species or soil at specific positions on the farm) and represents the SHUBIOMIC diversity of the agro ecosystem. It was used for mapping micronutrient rich or micronutrient limited bio-resource diversity on the farm in a SHUBIOMIC Diversity Unit (SDU) mapping design.

6. The resulting map was the end point or output of the project. It can be used to influence decisions regarding intervening variables that have implications on nutraceutical and economic security e.g. National policy, Market ethics and dynamics, Price level differentiation, Labour and time allocation, corporations, Land use management, Way of life, etc.

Appendix 1.2a Rainfall amount (mm)* in Vihiga district during the year 2009

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tot
Vihiga DHQS	13.7 (3)	85.6 (8)	25.1 (2)	138.3 (8)	163.7 (12)	194.6 (18)	128.6 (10)	84.1 (10)	230 (22)	380.4 (24)	218 (11)	162 (11)	1824.1 (139)

**Number of Rainy Days in each month is given in parentheses*

Appendix 1.2b: Rainfall amount (mm) in Vihiga district in the year 2008

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec*	Tot
Sabatia Division	51.55 (5)	83.0 (8)	165.7 (15)	251.9 (14)	179.9 (22)	83.2 (8)	324.6 (22)	294.5 (15)	234.5 (16)	181.9 (19)	150.2 (12)	159 (9)	2159.95 (165)
Vihiga Division	10 (2)	92.5 (9)	220.6 (21)	510 (2)	459 (18)	449 (14)	205 (21)	205 (19)	221.9 (20)	227 (25)	260 (13)	101 (15)	3161.0 (179)

**Number of Rainy Days in each month is given in parentheses*

Appendix 1.2c: Rainfall amount and number of wet days in Emuhaya district in the year 2009

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Amount (mm)	25	35	30	40	115	76	80	50	80	57.1	101.8	122.5
No. of wet days	2	8	5	10	12	8	12	8	10	7	16	13

Appendix 3.1a: Nutrahealth implied Ionomic Variation (NHIV) grading Method

The following procedure developed by Akundabweni et al. (2009), was used to derive the NHIV grades for plant accessions.

Step 1:

The mineral concentration data in PPM was entered into excel worksheet (Sheet A1)

Step 2:

The five-category delimitation rule was applied separately for each element. The concentration range for each element was separated into five suitably chosen groups, or intervals chosen such that the interval ranges were equal to each other, and the interval midpoints were simple numbers. The interval boundaries were then expressed in the formula bar using the IF function to assign NHIV rank values ranging from 1 for the highest density interval to 5 for the lowest density interval as shown in sheet A4.2: [The formula bar for potassium (K) ranks, for example was entered as:

```
=IF(E2<15000,5,IF(E2<30000,4,IF(E2<45000,3,IF(E2<60000,2,IF(E2<75000,1)))))]
```

Step 3:

A worksheet of the mineral ranks was then entered and used to calculate the geometric mean of all the six elements for each sample (accession). The geometric mean values were then used to assign NHIV grades ranging from 1 to 10 to the accessions whereby the accessions with the least geometric mean got the highest marks (table A4.1) using a predetermined scoring scale given in Table A4.4

Appendix 3.1b: Mineral concentration data in PPM for 2009 long and short rains plant samples

District	View/ Walkshed	Sample code	Sample	K	Ca	Fe	Sr	Mn	Zn
Emuhaya	LBKV	L09F11ENU P136	Crotalaria 11	25150.00	17800.00	485.00	80.65	293.00	81.10
Emuhaya	RBKF	L09F12ENU P139	Cowpeas 12	43400.00	34600.00	2360.00	162.00	764.00	64.00
Emuhaya	RBKV	L09F13ENU P147	Amaranth 13	47600.00	24700.00	1200.00	174.00	283.00	201.00
Emuhaya	RBKV	L09F13ENU P147	Amaranth 13	42900.00	16600.00	707.00	93.90	604.00	54.90
Emuhaya	LFV	L09F14ENU P20	Maize	16600.00	2435.00	121.50	4.83	LDL	37.80
Emuhaya	LFV	L09F14ENU P8	Beans black	14400.00	3210.00	170.00	10.60	LDL	38.10
Emuhaya	LBKV	L09F15ENU P153	Solanum 15	41900.00	12500.00	453.50	62.90	116.00	42.50
Emuhaya	LFV	L09F19ENU P157	Cowpeas 19	19800.00	23800.00	3200.00	154.00	882.00	51.50
Vihiga	LFV	L09F1VNU P118	Pumpkin leaves 1	44300.00	90200.00	3220.00	421.00	283.00	79.70
Emuhaya	RBKV	L09F21ENU P159	Crotalaria 21	23350.00	8040.00	793.00	40.00	150.50	54.15
Emuhaya	LBKF	L09F22ENU P162	Kale 22	27500.00	29850.00	931.50	194.00	3135.00	177.00
Emuhaya	LBKF	L09F23ENU P163	Amaranth 23	50350.00	21050.00	3810.00	143.00	188.00	73.65
Vihiga	LFF	L09F2VNU P19	Beans (kikuyu)	20650.00	3630.00	177.00	9.82	LDL	40.85
Vihiga	LBKF	L09F30VNU P179	Jute plant 30	46200.00	26700.00	560.00	108.00	268.00	37.20
Vihiga	RBKV	L09F5VNU P121	Spider flower 5	30800.00	17200.00	1730.00	102.00	129.00	88.40
Vihiga	RBKV	L09F5VNU P123	Cowpeas 5	36000.00	32000.00	1030.00	131.00	252.50	113.00
Vihiga	LBKF	L09F5VNU P124	Jute plant 5	39700.00	18500.00	4910.00	83.20	248.00	83.80
Vihiga	LBKF	L09F6VNU P126	Solanum 6	28250.00	22700.00	1850.00	188.00	118.50	43.30
Vihiga	LBKF	L09F7VNU P128	Solanum 7	58266.67	15433.33	3986.67	101.17	692.33	190.67
Vihiga	LBKF	L09F9VNU P134	Cowpeas 9	47350.00	27400.00	2060.00	180.50	248.00	72.40
Vihiga	LFF	S09F1VNU P91	Spider flower	54400.00	28800.00	10400.00	201.00	1010.00	178.00
Vihiga	NHBF	S09F26VNU P40	Spider flower (8)	43700.00	56000.00	1390.00	263.00	290.00	66.90
Vihiga	NHBF	S09F30VNU P74	Amaranth (6)	70700.00	37966.67	1256.67	168.67	272.67	151.00
Vihiga	NHBF	S09F31VNU P64	Amaranth (7)	58100.00	32766.67	1466.67	150.33	249.00	106.27
Emuhaya	NHBF	S09F33ENU P87	Local kale (6)	33800.00	40300.00	1109.50	313.50	220.75	235.35
Emuhaya	NHBF	S09F34ENU P59	Spider flower (8)	36233.33	30266.67	2406.67	195.33	260.67	93.07
Emuhaya	NHBF	S09F35ENU P61	Spider flower (7)	38066.67	21000.00	1236.67	139.00	214.00	156.23
Emuhaya	NHBF	S09F37ENU P99	Spider flower (7)	31533.33	24133.33	2940.00	113.67	308.33	128.33
Emuhaya	LFS	S09F38ENU P68	Crotalaria (6)	20550.00	15400.00	486.50	97.30	358.00	64.35
Emuhaya	NHBF	S09F38ENU P70	Amaranth (7)	68366.67	25966.67	1386.67	125.67	261.67	152.67

Emuhaya	NHBF	S09F39ENU P105	Jute plant (6)	39200.00	18900.00	1610.00	116.00	252.67	40.57
Emuhaya	NHBF	S09F39ENU P54	Pumpkin leaves (6)	33150.00	21050.00	1730.00	148.00	132.50	85.55
Emuhaya	NHBF	S09F40ENU P84	Amaranth (6)	69800.00	16400.00	2600.00	102.00	337.00	87.00
Vihiga	NHBF	S09F5VNU P92	Crotalaria (6)	54533.33	13500.00	940.33	60.73	795.33	141.00
Vihiga	NHBF	S09F5VNU P93	Solanum	33500.00	20800.00	425.00	133.50	493.50	146.50
Vihiga	NHBF	S09F5VNU P94	Amaranth (3)	48366.67	29733.33	1083.33	232.67	167.33	78.17
Vihiga	NHBF	S09F5VNU P96	Spider flower (6)	49266.67	28866.67	509.00	78.50	88.40	109.67
Vihiga	NHBF	S09F6VNU P49	Cowpeas	25000.00	29800.00	806.00	225.00	391.33	50.27
Emuhaya	RBKV	L09F13ENU P147	Amaranth 13	42900.00	16600.00	707.00	93.90	604.00	54.90
Emuhaya	LFV	L09F19ENU P158	Cowpeas 20	19800.00	23800.00	3200.00	154.00	882.00	51.50
Vihiga	RBKF	L09F1VNU P182	Spider flower 1	54400.00	28800.00	10400.00	201.00	1010.00	178.00
Vihiga	NHBF	S09F5VNU P93	Solanum	33500.00	20800.00	425.00	133.50	493.50	146.50

Appendix 3.1c: Mineral concentration ranking of 2009 long and short rains' plant samples

Sample code	Sample	K(ppm)	K rank	Ca(ppm)	Ca Rank	Fe(ppm)	Fe Rank	Sr(ppm)	Sr Rank	Mn(ppm)	Mn Rank	Zn(ppm)	Zn Rank
L09F11ENU P136	Crotalaria 11	25150.00	4.00	17800.00	5.00	485.00	5.00	80.65	5.00	293.00	4.00	81.10	5.00
L09F12ENU P139	Cowpeas 12	43400.00	3.00	34600.00	4.00	2360.00	5.00	162.00	4.00	764.00	2.00	64.00	5.00
L09F13ENU P142	cassava lvs 13	20800.00	4.00	24400.00	4.00	846.00	5.00	98.50	5.00	419.00	4.00	176.00	4.00
L09F13ENU P147	Amaranth 13	47600.00	2.00	24700.00	4.00	1200.00	5.00	174.00	4.00	283.00	4.00	201.00	3.00
L09F13ENU P147	Amaranth 13	42900.00	3.00	16600.00	5.00	707.00	5.00	93.90	5.00	604.00	3.00	54.90	5.00
L09F14ENU P20	maize	16600.00	4.00	2435.00	5.00	121.50	5.00	4.83	5.00	LDL	5.00	37.80	5.00
L09F14ENU P8	black beans	14400.00	5.00	3210.00	5.00	170.00	5.00	10.60	5.00	LDL	5.00	38.10	5.00
L09F15ENU P153	Solanum 15	41900.00	3.00	12500.00	5.00	453.50	5.00	62.90	5.00	116.00	5.00	42.50	5.00
L09F19ENU P157	Cowpeas 19	19800.00	4.00	23800.00	4.00	3200.00	4.00	154.00	4.00	882.00	2.00	51.50	5.00
L09F1VNU P118	Pumpkin leaves	44300.00	3.00	90200.00	1.00	3220.00	4.00	421.00	1.00	283.00	4.00	79.70	5.00
L09F21ENU P159	Crotalaria 21	23350.00	4.00	8040.00	5.00	793.00	5.00	40.00	5.00	150.50	5.00	54.15	5.00
L09F22ENU P162	Kales 22	27500.00	4.00	29850.00	4.00	931.50	5.00	194.00	4.00	3135.0	1.00	177.00	4.00
L09F23ENU P163	Amaranth 23	50350.00	2.00	21050.00	5.00	3810.00	4.00	143.00	4.00	188.00	5.00	73.65	5.00
L09F2VNU P19	kikuyu beans	20650.00	4.00	3630.00	5.00	177.00	5.00	9.82	5.00	LDL	5.00	40.85	5.00
L09F30VNU P179	Jute plant luo 30	46200.00	2.00	26700.00	4.00	560.00	5.00	108.00	4.00	268.00	4.00	37.20	5.00
L09F5VNU P121	Spider flower 5	30800.00	3.00	17200.00	5.00	1730.00	5.00	102.00	4.00	129.00	5.00	88.40	5.00
L09F5VNU P123	Cowpeas 5	36000.00	3.00	32000.00	4.00	1030.00	5.00	131.00	4.00	252.50	4.00	113.00	4.00
L09F5VNU P124	Jute plant 5	39700.00	3.00	18500.00	5.00	4910.00	4.00	83.20	5.00	248.00	5.00	83.80	5.00
L09F6VNU P126	Solanum 6	28250.00	4.00	22700.00	4.00	1850.00	5.00	188.00	4.00	118.50	5.00	43.30	5.00
L09F7VNU P128	Solanum 7	58266.67	2.00	15433.33	5.00	3986.67	4.00	101.17	4.00	692.33	3.00	190.67	3.00
L09F9VNU P134	Cowpeas 9	47350.00	2.00	27400.00	4.00	2060.00	5.00	180.50	4.00	248.00	5.00	72.40	5.00
S09F1VNU P91	Spider flower	54400.00	2.00	28800.00	4.00	10400.0	1.00	201.00	3.00	1010.0	1.00	178.00	4.00
S09F26VNU P40	Spider flower (8)	43700.00	3.00	56000.00	3.00	1390.00	5.00	263.00	3.00	290.00	4.00	66.90	5.00
S09F30VNU P74	Amaranth (6)	70700.00	1.00	37966.67	4.00	1256.67	5.00	168.67	4.00	272.67	4.00	151.00	4.00
S09F31VNU P64	Amaranth (7)	58100.00	2.00	32766.67	4.00	1466.67	5.00	150.33	4.00	249.00	5.00	106.27	4.00
S09F33ENU P87	Local kale (6)	33800.00	3.00	40300.00	4.00	1109.50	5.00	313.50	2.00	220.75	5.00	235.35	3.00
S09F34ENU P59	Spider flower (8)	36233.33	3.00	30266.67	4.00	2406.67	5.00	195.33	4.00	260.67	4.00	93.07	4.00
S09F35ENU P61	Spider flower (7)	38066.67	3.00	21000.00	5.00	1236.67	5.00	139.00	4.00	214.00	5.00	156.23	4.00
S09F37ENU P99	Spider flower (7)	31533.33	3.00	24133.33	4.00	2940.00	4.00	113.67	4.00	308.33	4.00	128.33	4.00

S09F38ENU P68	Crotalaria (6)	20550.00	4.00	15400.00	5.00	486.50	5.00	97.30	5.00	358.00	4.00	64.35	5.00
S09F38ENU P70	Amaranth (7)	68366.67	1.00	25966.67	4.00	1386.67	5.00	125.67	4.00	261.67	4.00	152.67	4.00
S09F39ENU P105	Jute plant (6)	39200.00	3.00	18900.00	5.00	1610.00	5.00	116.00	4.00	252.67	4.00	40.57	5.00
S09F39ENU P54	Pumpkin lves (6)	33150.00	3.00	21050.00	5.00	1730.00	5.00	148.00	4.00	132.50	5.00	85.55	5.00
S09F40ENU P84	Amaranth (6)	69800.00	1.00	16400.00	5.00	2600.00	4.00	102.00	4.00	337.00	4.00	87.00	5.00
S09F5VNU P92	Crotalaria (6)	54533.33	2.00	13500.00	5.00	940.33	5.00	60.73	5.00	795.33	2.00	141.00	4.00
S09F5VNU P93	Solanum	33500.00	3.00	20800.00	5.00	425.00	5.00	133.50	4.00	493.50	4.00	146.50	4.00
S09F5VNU P94	Amaranth (3)	48366.67	2.00	29733.33	4.00	1083.33	5.00	232.67	3.00	167.33	5.00	78.17	5.00
S09F5VNU P96	Spider flower (6)	49266.67	2.00	28866.67	4.00	509.00	5.00	78.50	5.00	88.40	5.00	109.67	4.00
S09F6VNU P49	Cowpeas	25000.00	4.00	29800.00	4.00	806.00	5.00	225.00	3.00	391.33	4.00	50.27	5.00
L09F13ENU P147	Amaranth 13	42900.00	3.00	16600.00	5.00	707.00	5.00	93.90	5.00	604.00	3.00	54.90	5.00
L09F19ENU P158	Cowpeas 20	19800.00	4.00	23800.00	4.00	3200.00	4.00	154.00	4.00	882.00	2.00	51.50	5.00
S09F5VNU P93	Solanum	33500.00	3.00	20800.00	5.00	425.00	5.00	133.50	4.00	493.50	4.00	146.50	4.00

Appendix 3.1d: NHIV grading for 2009 long and short rains plant samples

View-Walkshed	Sample code	Sample	K Rank	Ca Rank	Fe Rank	Sr Rank	Mn Rank	Zn Rank	GM	NHIV* grade	Grade* description
LFF	S09F1VNU P91	Spider plant	2	4	1	3	1	4	2.1398	8	High
LFV	L09F1VNU P118	Pumpkin lvs	3	1	4	1	4	5	2.4929	7	Medium
NHBF	S09F33ENU P87	Local Kales(6)	3	4	5	4	5	1	3.2598	5	Medium
LBKF	L09F22ENU P162	Kales	4	4	5	4	1	4	3.2951	5	Medium
NHBF	S09F30VNU P74	Amaranth (6)	1	4	5	4	4	4	3.2951	5	Medium
NHBF	S09F38ENU P70	Amaranth (7)	1	4	5	4	4	4	3.2951	5	Medium
LBKF	L09F7VNU P128	Solanum	2	5	4	4	3	3	3.3604	5	Medium
NHBF	S09F40ENU P84	Amaranth (6)	1	5	4	4	4	5	3.4200	5	Medium
RBKV	L09F13ENU P147	Amaranth 2	2	4	5	4	4	3	3.5255	5	Medium
NHBF	S09F5VNU P92	Crotalaria (6)	2	5	5	5	2	4	3.5495	4	Low
RBKF	L09F12ENU P139	Cow peas	3	4	5	4	2	5	3.6591	4	Low
LFV	L09F19ENU P157	Cow peas	4	4	4	4	2	5	3.6986	4	Low
LFV	L09F19ENU P158	Cow peas 20	4	4	4	4	2	5	3.6986	4	Low
NHBF	S09F26VNU P40	Spider plant (8)	3	3	5	3	4	5	3.7316	4	Low
NHBF	S09F5VNU P94	Amaranth (3)	2	4	5	3	5	5	3.7977	4	Low
NHBF	S09F37ENU P99	Spider plant (7)	3	4	4	4	4	4	3.8127	4	Low
LBKF	L09F30VNU P179	Jute plant (luo)	2	4	5	4	4	5	3.8388	4	Low
NHBF	S09F31VNU P64	Amaranth 2 (7)	2	4	5	4	5	4	3.8388	4	Low
RBKV	L09F5VNU P123	Cow peas	3	4	5	4	4	4	3.9572	3	Low
NHBF	S09F34ENU P59	Spider plant (8)	3	4	5	4	4	4	3.9572	3	Low
LBKF	L09F23ENU P163	Amaranth	2	5	4	4	5	5	3.9842	3	Low
LBKF	L09F9VNU P134	Cow peas	2	4	5	4	5	5	3.9842	3	Low
NHBF	S09F5VNU P96	Spider plant (6)	2	4	5	5	5	4	3.9842	3	Low
NHBF	S09F5VNU P93	Solanum	3	5	5	4	4	4	4.1071	3	Low
NHBF	S09F6VNU P49	Cow peas	4	4	5	3	4	5	4.1071	3	Low
NHBF	S09F5VNU P93	Solanum	3	5	5	4	4	4	4.1071	3	Low
RBKV	L09F13ENU P147	Amaranth 2	3	5	5	5	3	5	4.2172	3	Low
RBKV	L09F13ENU P147	Pumpkin lves 13	3	5	5	5	3	5	4.2172	3	Low
NHBF	S09F35ENU P61	Spider plant (7)	3	5	5	4	5	4	4.2628	3	Low

NHBF	S09F39ENU P105	Jute plant (6)	3	5	5	4	4	5	4.2628	3	Low
LBKF	L09F13ENU P142	cassava lvs	4	4	5	5	4	4	4.3089	3	Low
RBKV	L09F5VNU P121	Spider plant	3	5	5	4	5	5	4.4243	2	Low
LBKF	L09F5VNU P124	Jute plant	3	5	4	5	5	5	4.4243	2	Low
NHBF	S09F39ENU P54	Pumpkin lves (6)	3	5	5	4	5	5	4.4243	2	Low
LBKF	L09F6VNU P126	Solanum	4	4	5	4	5	5	4.4721	2	Low
LBKV	L09F15ENU P153	Solanum	3	5	5	5	5	5	4.5919	2	Low
LBKV	L09F11ENU P136	Crotalaria	4	5	5	5	4	5	4.6416	2	Low
LFS	S09F38ENU P68	Crotalaria (6)	4	5	5	5	4	5	4.6416	2	Low
LFV	L09F14ENU P20	Maize	4	5	5	5	5	5	4.8175	1	Low
LFF	L09F2VNU P19	kikuyu beans	4	5	5	5	5	5	4.8175	1	Low
RBKV	L09F21ENU P159	Crotalaria	4	5	5	5	5	5	4.8175	1	Low
LFV	L09F14ENU P8	black beans	5	5	5	5	5	5	5.0000	1	Low

**The Predetermined NHIV grades scoring scale shown in Table A4.4 below was used to derive the values shown.*

Appendix 3.1e: Predetermined NHIV grades scoring scale

Pre-scaled GM range	NHIV grades	NHIV grade description
1.0-1.4	10	Highly Exceptional
1.5-1.8	9	Highly Exceptional
1.9-2.3	8	Highly Exceptional
2.4-2.7	7	Moderately Exceptional
2.8-3.1	6	Moderately Exceptional
3.2-3.5	5	Moderately Exceptional
3.6-3.9	4	Less Exceptional
4.0-4.3	3	Less Exceptional
4.4-4.7	2	Less Exceptional
4.8-5.0	1	Less Exceptional

Source: Akundabweni et al. (2009)

Appendix 3.2a: Two factor Analysis of variance table for soil and plant NHIV grades for 2008 samples

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	112.5522	66	1.705337	0.750572	0.87679	1.503607
Columns	437.0448	1	437.0448	192.3571	3.12E-21	3.986269
Error	149.9552	66	2.272049			
Total	699.5522	133				

Appendix 3.2b: Single factor Analysis of variance table for soil and plant NHIV grades for 2008 samples

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	437.0448	1	437.0448	219.7648	7.02E-30	3.912875
Within Groups	262.5075	132	1.988693			
Total	699.5522	133				

Appendix 3.3 **Nutrahealth-implied Ionomic Variants grades for plant accessions for three consecutive seasons in Esibuye and Vihiga**

	District	SDU section	Accession code	Species	NHIV grade	Ionomic variation content ranks					
						K	Ca	Fe	Sr	Mn	Zn
Exceptionally Core (Highly Exceptional) collections - 1.4%											
1	Esibuye	LFV	L09F15ENU P5	Beans (wairimu)	8	2	4	1	3	1	4
2	Vihiga	LFF	S09F1VNU P91	Spider plant	8	2	4	1	3	1	4
Core (Moderately Exceptional) collections - 14.8%											
3	Esibuye	LBKF	S08F17EEbyNUP468	Pumpkin leaves	7	3	1	5	1	5	5
4	Vihiga	LBKF	S08F7VEmdNUP412	Pumpkin leaves	7	3	1	5	1	5	5
5	Vihiga	LFV	L09F1VNU P118	Pumpkin leaves	7	3	1	4	1	4	5
6	Vihiga	RBKF	S08F1VIkbNUP382	Amaranth	7	3	4	5	3	2	1
7	Esibuye	LBKF	S08F24EEbsNUP492	Pumpkin leaves	6	4	3	2	3	2	5
8	Vihiga	LBKF	S08F8VEmdNUP424	Amaranth	6	4	4	5	3	1	4
9	Vihiga	LBKF	S08F3VIkbNUP557	Solanum	6	2	5	1	5	3	5
10	Esibuye	LBKF	S08F13EEbsNUP450	Amaranth	5	2	5	5	5	2	4
11	Esibuye	LBKF	S08F20EEbyNUP479	Amaranth	5	4	4	5	5	1	5
12	Esibuye	LBKF	S08F23EEbyNUP491	Pumpkin leaves	5	3	2	5	2	4	5
13	Esibuye	LBKF	L09F22ENU P162	Kales	5	4	4	5	4	1	4
14	Esibuye	LFV	L09F14ENU P116	Beans varieties	5	1	4	5	4	4	4
15	Esibuye	LFV	L09F15ENU P3	Beans (zindoli)	5	2	5	5	5	2	4
16	Esibuye	NHBF	S08F16EEbyNUP466	Pumpkin leaves	5	1	5	3	5	5	4
17	Esibuye	NHBF	S09F33ENU P87	Local Kales (6)*	5	3	4	5	4	5	1
18	Esibuye	NHBF	S09F38ENU P70	Amaranth (7)*	5	1	4	5	4	4	4
19	Esibuye	NHBF	S09F40ENU P84	Amaranth (6)*	5	1	5	4	4	4	5
20	Esibuye	RBKF	L09F26ENU P2	Maize	5	1	4	5	4	4	4
21	Esibuye	RBKV	L09F13ENU P147	Amaranth 2	5	2	4	5	4	4	3
22	Vihiga	LBKF	L09F7VNU P128	Solanum	5	2	5	4	4	3	3
23	Vihiga	NHBF	S09F30VNU P74	Amaranth (6)*	5	1	4	5	4	4	4
Reserve (Less Exceptional) collections -83.8%											
24	Esibuye	LBKF	S08F21EEbyNUP568	Solanum	4	1	5	5	5	5	5
25	Esibuye	LBKF	S08F25EEbsNUP500	Pumpkin leaves	4	3	4	2	4	5	5
26	Esibuye	LBKF	L09F24ENU P115	Pumpkin leaves	4	2	4	5	4	5	4
27	Esibuye	LFV	L09F19ENU P157	Cowpeas	4	4	4	4	4	2	5
28	Esibuye	LFV	L09F20ENU P158	Cowpeas	4	4	4	4	4	2	5
29	Esibuye	NHBF	S09F37ENU P100	Cowpeas	4	4	4	4	4	2	4
30	Esibuye	NHBF	S09F37ENU P99	Spider plant (7)*	4	3	4	4	4	4	4
31	Esibuye	NHBF	S09F39ENU P52	Crotalaria	4	3	4	4	4	4	4
32	Esibuye	RBKF	L09F12ENU P139	Cowpeas	4	3	4	5	4	2	5
33	Vihiga	LBKF	S08F2VIkbNUP388	Amaranth 2	4	2	4	4	4	4	5
34	Vihiga	LBKF	S08F8VEmdNUP424	Amaranth	4	4	4	5	3	1	4
35	Vihiga	LBKF	S08F8VEmdNUP560	Amaranth	4	3	4	5	3	4	5
36	Vihiga	LBKF	S08F26VIkbNUP504	Pumpkin leaves	4	3	3	4	4	5	5
37	Vihiga	LBKF	L09F30VNU P179	Jute plant (luo)	4	2	4	5	4	4	5
38	Vihiga	NHBF	S09F26VNU P40	Spider plant (8)*	4	3	3	5	3	4	5
39	Vihiga	NHBF	S09F31VNU P64	Amaranth 2 (7)*	4	2	4	5	4	5	4
40	Vihiga	NHBF	S09F5VNU P92	Crotalaria (6)*	4	2	5	5	5	2	4
41	Vihiga	NHBF	S09F5VNU P94	Amaranth (3)*	4	2	4	5	3	5	5
42	Esibuye		S09F35ENU P111	Pumpkin leaves	3	3	4	5	4	5	4

Reserve collection continued											
43	Esibuye	LBKF	S08F11EEbsNUP434	Pumpkin leaves	3	2	4	5	4	5	5
44	Esibuye	LBKF	S08F12EEbsNUP443	Pumpkin leaves	3	2	5	5	5	5	5
45	Esibuye	LBKF	S08F15EEbsNUP463	Cowpeas	3	3	4	5	5	3	5
46	Esibuye	LBKF	S08F15EEbsNUP463	Cowpeas	3	4	4	5	5	3	5
47	Esibuye	LBKF	S08F16EEbyNUP566	Solanum	3	2	4	5	5	5	5
48	Esibuye	LBKF	S08F21EEbyNUP482	Pumpkin leaves	3	2	5	5	5	5	5
49	Esibuye	LBKF	S08F21EEbyNUP484	Pumpkin leaves	3	3	4	5	4	5	5
50	Esibuye	LBKF	S08F23EEbyNUP486	Solanum	3	3	4	4	5	5	5
51	Esibuye	LBKF	S08F23EEbyNUP489	Crotalaria	3	2	5	5	5	4	5
52	Esibuye	LBKF	S08F24EEbsNUP496	Jute plant	3	2	5	5	5	4	5
53	Esibuye	LBKF	S08F24EEbsNUP494	Cow peas	3	3	5	5	4	4	5
54	Esibuye	LBKF	L09F12ENU P4	Beans (lipala)	3	3	4	5	5	5	4
55	Esibuye	LBKF	L09F13ENU P142	Cassava leaves	3	4	4	5	5	4	4
56	Esibuye	LBKF	L09F23ENU P163	Amaranth	3	2	5	4	4	5	5
57	Esibuye	LBKF	L09F9VNU P134	Cowpeas	3	2	4	5	4	5	5
58	Esibuye	LFF	S08F11EEbsNUP433	Solanum	3	4	4	5	4	4	5
59	Esibuye	LFF	S08F18EEbyNUP473	Cowpeas	3	5	4	5	4	3	5
60	Esibuye	LFF	S08F18EEbyNUP473	Cowpeas	3	5	4	5	4	3	5
61	Esibuye	LFF	S08F18EEbyNUP567	Amaranth 2	3	3	4	5	4	5	5
62	Esibuye	LFV	L09F12ENU P10	Beans(kikuyu)	3	3	5	5	4	5	4
63	Esibuye	NHBF	S08F15EEbsNUP461	Pumpkin leaves	3	3	4	5	4	5	5
64	Esibuye	NHBF	S08F15EEbsNUP564	Amaranth	3	3	4	5	4	5	5
65	Esibuye	NHBF	S08F16EEbyNUP465	Amaranth 2	3	2	5	5	5	5	5
66	Esibuye	NHBF	S09F34ENU P59	Spider plant (8)*	3	3	4	5	4	4	4
67	Esibuye	NHBF	S09F35ENU P61	Spider plant (7)*	3	3	5	5	4	5	4
68	Esibuye	NHBF	S09F39ENU P105	Jute plant (6)*	3	3	5	5	4	4	5
69	Esibuye	RBKF	S08F13EEbsNUP453	Cowpeas	3	5	4	5	4	3	5
70	Esibuye	RBKF	S08F13EEbsNUP453	Cowpeas	3	5	4	5	3	3	5
71	Esibuye	RBKF	S08F21EEbyNUP483	Cowpeas	3	4	4	5	4	4	5
72	Esibuye	RBKV	L09F13ENU P147	Amaranth	3	2	4	5	4	4	3
73	Esibuye	RBKV	L09F13ENU P147	Amaranth	3	3	5	5	5	3	5
74	Vihiga	LBKF	S08F4VEmdNUP401	Pumpkin leaves	3	3	3	5	4	5	5
75	Vihiga	LBKF	S08F4VEmdNUP564	Amaranth 2	3	2	4	5	5	5	5
76	Vihiga	LBKF	S08F5VEmdNUP405	Amaranth	3	4	4	5	4	5	4
77	Vihiga	LBKF	S08F5VEmdNUP409	Amaranth 2	3	3	4	5	5	5	4
78	Vihiga	LBKF	S08F6VEmdNUP565	Cow peas	3	4	5	4	4	4	5
79	Vihiga	LBKF	S08F6VEmdNUP411	Amaranth 2	3	4	4	5	4	5	4
80	Vihiga	LBKF	S08F7VEmdNUP567	Amaranth 2	3	2	5	5	5	5	5
81	Vihiga	LBKF	S08F8VEmdNUP422	Spider plant	3	3	4	5	4	5	5
82	Vihiga	LBKF	S08F8VEmdNUP423	Amaranth 2	3	3	4	5	4	5	5
83	Vihiga	LBKF	S08F26VIkbNUP503	Amaranth	3	3	4	5	4	5	5
84	Vihiga	LBKF	S08F27VIkbNUP512	Pumpkin leaves	3	4	3	5	3	5	5
85	Vihiga	LBKF	S08F29VIkbNUP519	Pumpkin leaves	3	3	3	5	4	5	5
86	Vihiga	LBKF	S08F29VIkbNUP520	Solanum	3	3	4	5	4	5	5
87	Vihiga	LBKF	S08F30VEmdNUP571	Amaranth 2	3	3	4	5	4	5	5
88	Vihiga	NHBF	S09F26VNU P43	Cowpeas	3	3	4	5	4	4	5
89	Vihiga	NHBF	S09F5VNU P93	Solanum	3	3	5	5	4	4	4
90	Vihiga	NHBF	S09F5VNU P93	Solanum	3	3	5	5	4	4	4

Reserve collection continued											
91	Vihiga	NHBF	S09F5VNU P96	Spider plant (6)*	3	2	4	5	5	5	4
92	Vihiga	NHBF	S09F6VNU P49	Cow peas	3	4	4	5	3	4	5
93	Vihiga	RBKF	S08F28VIkbNUP514	Amaranth 2	3	3	4	5	4	5	4
94	Vihiga	RBKF	S08F28VIkbNUP570	Jute plant	3	3	4	5	5	4	4
95	Vihiga	RBKV	L09F5VNU P123	Cowpeas	3	3	4	5	4	4	4
96	Esibuye	LBKF	S08F13EEbsNUP449	Crotalaria	2	3	5	5	5	5	5
97	Esibuye	LBKF	S08F14EEbsNUP456	Cow peas	2	4	5	5	5	3	5
98	Esibuye	LBKF	S08F19EEbyNUP474	Jute plant	2	4	5	5	5	4	5
99	Esibuye	LBKF	S08F20EEbyNUP478	Jute plant	2	3	5	5	5	5	5
100	Esibuye	LBKF	S08F20EEbyNUP558	Solanum	2	3	5	4	5	5	5
101	Esibuye	LBKF	S08F24EEbsNUP495	Amaranth 2	2	3	5	5	4	5	5
102	Esibuye	LBKF	S08F25EEbsNUP497	Cow peas	2	4	5	5	5	4	5
103	Esibuye	LBKF	S08F25EEbsNUP499	Solanum	2	3	5	5	5	5	5
104	Esibuye	LBKF	S08F25EEbsNUP501	Local Kale	2	3	5	5	5	5	5
105	Esibuye	LBKF	S08F25EEbsNUP502	Amaranth	2	3	4	5	5	5	5
106	Esibuye	LBKV	L09F11ENU P136	Crotalaria	2	4	5	5	5	4	5
107	Esibuye	LBKV	L09F15ENU P153	Solanum	2	3	5	5	5	5	5
108	Esibuye	LFF	S08F18EEbyNUP472	Crotalaria	2	3	5	5	5	5	5
109	Esibuye	LFS	S09F38ENU P68	Crotalaria (6)*	2	4	5	5	5	4	5
110	Esibuye	NHBF	S08F14EEbsNUP458	Pumpkin leaves	2	3	5	5	5	5	5
111	Esibuye	NHBF	S08F25EEbsNUP498	Jute plant	2	3	5	5	5	5	5
112	Esibuye	NHBF	S09F39ENU P54	Pumpkin lvs(6)*	2	3	5	5	4	5	5
113	Vihiga	LBKF	S08F2VIkbNUP387	Solanum	2	3	5	5	-	5	5
114	Vihiga	LBKF	S08F4VEmdNUP563	Solanum	2	4	4	5	5	5	5
115	Vihiga	LBKF	S08F6VEmdNUP566	Spider plant	2	4	4	5	4	5	5
116	Vihiga	LBKF	S08F8VEmdNUP420	Pumpkin leaves	2	3	5	5	5	5	5
117	Vihiga	LBKF	S08F9VEmdNUP427	Solanum	2	3	5	5	5	5	5
118	Vihiga	LBKF	S08F26VIkbNUP505	Solanum	2	3	4	5	5	5	5
119	Vihiga	LBKF	S08F26VIkbNUP569	Jute plant	2	4	4	5	5	5	5
120	Vihiga	LBKF	S08F31VEmdNUP529	Amaranth 2	2	3	5	4	5	5	5
121	Vihiga	LBKF	S08F31VEmdNUP531	Cow peas	2	4	5	4	5	4	5
122	Vihiga	LBKF	L09F5VNU P124	Jute plant	2	3	5	4	5	5	5
123	Vihiga	LBKF	L09F6VNU P126	Solanum	2	4	4	5	4	5	5
124	Vihiga	LFF	S08F10VEmdNUP428	Solanum	2	3	5	5	5	5	5
125	Vihiga	RBKF	S08F28VIkbNUP513	Pumpkin leaves	2	4	4	5	4	5	5
126	Vihiga	RBKV	L09F5VNU P121	Spider plant	2	3	5	5	4	5	5
127	Esibuye	LBKF	S08F14EEbsNUP455	Jute plant	1	4	5	5	5	5	5
128	Esibuye	LBKF	S08F19EEbyNUP474	Jute plant	1	4	5	5	5	5	5
129	Esibuye	LFF	S08F20EEbyNUP568	Cassava leaves	1	4	5	5	5	5	5
130	Esibuye	LFV	L09F14ENU P20	Maize	1	4	5	5	5	5	5
131	Esibuye	LFV	L09F14ENU P8	Beans (black)	1	5	5	5	5	5	5
132	Esibuye	NHBF	S08F14EEbsNUP458	Pumpkin leaves	1	3	5	5	5	5	5
133	Esibuye	RBKV	L09F21ENU P159	Crotalaria	1	4	5	5	5	5	5
134	Vihiga	LBKF	S08F4VEmdNUP404	Jute plant	1	4	5	5	5	5	5
135	Vihiga	LBKF	S08F8VEmdNUP419	Crotalaria	1	4	5	5	5	5	5
136	Vihiga	LBKF	S08F28VIkbNUP571	Crotalaria	1	4	5	5	5	5	5
137	Vihiga	LBKF	S08F29VIkbNUP518	Cowpeas	1	4	5	5	5	5	5
138	Vihiga	LBKF	S08F30VEmdNUP556	Cowpeas	1	4	5	5	5	5	5

Reserve collection continued											
139	Vihiga	LBKF	S08F31VEmdNUP528	Jute plant	1	4	5	5	5	5	5
140	Vihiga	LFF	L09F2VNU P19	Beans (kikuyu)	1	4	5	5	5	5	5
141	Vihiga	NHBF	S08F28VIkbNUP516	Solanum	1	4	5	5	5	5	5
142	Vihiga	RBKF	S08F1VIkbNUP383	Jute plant	1	4	5	5	5	5	5

*The bracketed numeric indicate that the accessions had been sampled in an earlier study and scored the indicated NHIV grades

Appendix 4.1: Questionnaire

1. Give your preference order of crops on your farm from most preferable and used to least preferable and underutilized

2. (a) Which crops have always been on your farm since you were the owner?

   (b) Which ones did you recently introduce?

   (c) From where did you get the introduced crops?

   - Market
   - Neighbour
   - Other

(d) If (c) for what purpose? - Factory, Feed, Fibre, Food, Fuel, Horticulture, Medicine.

3. Which crops were found here a long time ago but appear to have disappeared?

4. Do you use fertilizer or manure? Where on the farm? On which crops?

5. Have you sub divided your farm into other parcels for your children? How many parcels/families?

6. Why have you allocated crops to the positions of your land the way they appear?

7. Most of the time, do you consume your own food and buy none, do you consume some and buy some or do you buy all? Which ones in each case?

8. Which crops do you plant together (intercrop) and for what reasons?

9. Which crops do you regard as providing good health?

10. Which people with expert advice have visited your farm?

NGOs	KARI	Church	Ministry
International organization	University	•	•

Appendix 4.2a: Procedure for determining crop popularization ranks

Women SDU operators were asked to rank the crops species in order of preference and use from the most preferred and used to the least preferred and used crop species.

Ranks were allocated scores ranging from 1 to10 for the least preferred to the most preferred respectively (the longest list had 10 items in it). The total points scored by each crop were found by multiplying the number of times it got a particular rank with the respective points and adding the Products. The top scoring crop was ranked first and vice versa for the least scoring crop.

Appendix 4.2b: Weighted popularization ranking matrix for crop species in Esibuye and Vihiga SDUs

crop	freqx10	freqx 9	freqx 8	freqx 7	freqx 6	freqx 5	freqx 4	freqx 3	freqx 2	freqx 1	Total* Score	Crop rank
Maize	210	9	16	7	-	5	-	-	-	-	247	1
Beans	-	153	8	-	6	-	-	-	-	-	167	2
Kales	50	18	16	7	24	-	-	-	-	-	115	3
Cow peas	-	-	48	49	-	5	-	-	-	-	102	4
Bananas	20	9	24	14	18	-	8	-	-	1	94	5
Amaranth	9	8	7	6	10	4	6	-	1	-	51	6
Jute plant	-	9	8	7	12	6	-	3	-	-	45	7
Pumpkin leaves	10	-	24	-	-	10	-		-	-	44	8
Sweet potato	-	18	-	7	6	-	4	3	-	-	38	9
Cassava	10	-	16	-	-	-	-	9	2	-	37	10
Spider plant	-	9	8	14	-	-		-	-	-	31	11
Solanum	-	18	-	7	-	-	4	-	-	-	29	12
Sorghum	-	-	8	7	6	-	-	-	-	-	21	13
Local kale	-	-	8	-	6	-	-	-	2	-	16	14
Pumpkin fruit	-	-	-	7	6	-	-	-	2	-	15	15
Avocadoes	-	-	-	-	-	10	4	-	-	-	14	16
Napier grass	-	-	-	-	6		4	-	-	-	10	17
Crotalaria	-	-	-	-	-	5	4	-	-	-	9	18
Guavas	-	-	-	-	-	5	4	-	-	-	9	19
Dania	-	-	8	-	-	-	-	-	-	-	8	20
Ground nuts	-	-	8	-	-	-	-	-	-	-	8	21
Arrow roots	-	-	-	7	-	-	-	-	-	-	7	22
Tea	-	-	-	-	-	5	-	-	2	-	7	23
Finger millet	-	-	-	-	-	-	-	3	-	-	3	24

Appendix 4.3 ANOVA table for Crop category abundance and allocationing on the SHUB-Ionomic Diversity Unit (SDU)

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	5170.529	7	738.647	3.044672	0.005708	2.092381
Within Groups	27171.56	112	242.6032			
Total	32342.09	119				

Appendix 4.4: Locationing of nutrahealth implied ionomic variants (NHIVs) on the S SHUB-Ionomic Diversity Units in 2009

View-walk section	NHIV Grade 8	NHIV Grade 7	NHIV Grade 5	NHIV Grade 4	NHIV Grade 3	NHIV Grade 2	NHIV Grade 1
NHBF	None	None	Amaranth S09F30VNU P74; S09F38ENU P70; S09F40ENU P84; Local kale S09F33ENU P87	Amaranth S09F31VNU P64; S09F5VNU P94; Crotalaria S09F39ENU P52; S09F5VNU P92; pider plant S09F26VNU P40; S09F37ENU P99; Cowpeas S09F37ENU P100	CowpeasS09F26VNU P43; S09F6VNU P49; Spider plant S09F34ENU P59; S09F35ENU P61; S09F5VNU P96; Jute plant S09F39ENU P105; Solanum S09F5VNU P93	Pumpkin leaves S09F39ENU P54	None
LBKF	None	None	Kales L09F22ENU P162; Solanum L09F7VNU P128	Pumpkin leaves L09F24ENU P115; Jute plant L09F30VNU P179	beans L09F12ENU P4; cassava lvs L09F13ENU P142; Amaranth; L09F23ENU P163; Cowpeas L09F9VNU P134	Jute plant L09F5VNU P124; SolanumL09F6VNU P126	None
LBKV	None	None	None	None	None	Crotalaria L09F11ENU P136; Solanum L09F15ENU P153	None
RBKF	None	None	Maize L09F26ENU P2	Cow peas L09F12ENU P139	None	None	None
RBKV	None	None	Amaranth 09F13ENU P147	None	Cowpeas L09F5VNU P123	Spider plant L09F5VNU P121	CrotalariaL09F21ENU P159
LFF	Spider plant S09F1VNU P91	None	None	None	None	None	Beans L09F2VNU P19
LFS	None	None	None	None	None	CrotalariaS09F38ENU P68	
LFV	Beans L09F15ENU P5	Pumpkin leaves L09F1VNU P118	Beans L09F14ENU P116; L09F15ENU P3	Cowpeas L09F19ENU P157; L09F19ENU P158	Beans L09F12ENU P10	None	Maize L09F14ENU P20; BeansL09F14ENU P8

Appendix 4.5: Locationing of nutrahealth implied ionomic variants (NHIVs) on the SHUB-Ionomic Diversity Units in 2008

View-walk section	NHIV Grade 7	NHIV Grade 6	NHIV Grade 5	NHIV Grade 4	NHIV Grade 3	NHIV Grade 2	NHIV Grade 1
NHBF	None	None	Pumpkin leaves S08F16EEbyNUP466	None	Pumpkin leaves S08F15EEbsNUP461; Amaranth S08F15EEbsNUP564; S08F16EEbyNUP465	Pumpkin leaves S08F14EEbsNUP458; Jute plant S08F25EEbsNUP498	Solanum S08F28VIkb NUP516; Pumpkin leaves S08F14EEbs NUP458
LBKF	Pumpkin leaves S08F7VEmdN UP412S08F17E EbyNUP468	Amaranth S08F8VEmdNUP4 24; Solanum S08F3VIkbNUP55 7; pumpkin leaves S08F24EEbsNUP4 92	Amaranth S08F13EEbsNUP450 S08F20EEbyNUP479 Pumpkin leaves S08F23EEbyNUP491	Pumpkin leaves S08F26VIkbNUP 504 S08F25EEbsNUP 500 Amaranth S08F2VIkbNUP3 88 S08F8VEmdNUP 424S08F8VEmd NUP560Solanum S08F21EEbyNUP 568	Pumpkin leaves S08F4VEmdNUP401 S08F27VIkbNUP512 S08F29VIkbNUP519 S08F11EEbsNUP434 S08F12EEbsNUP443 S08F21EEbyNUP482 S08F21EEbyNUP484; Amaranth S08F4VEmdNUP564 S08F5VEmdNUP405 S08F5VEmdNUP409 S08F7VEmdNUP567 S08F8VEmdNUP423 S08F26VIkbNUP503 S08F30VEmdNUP571 S08F6VEmdNUP411 Cowpeas S08F6VEmdNUP565; S08F15EEbsNUP463; S08F15EEbsNUP463; S08F24EEbsNUP494 Spider plant S08F8VEmdNUP422; Solanum	Jute plant S08F26VIkbNUP569; S08F19EEbyNUP474; S08F20EEbyNUP478 Solanum S08F2VIkbNUP387 S08F4VEmdNUP563 S08F9VEmdNUP427 S08F26VIkbNUP505 S08F20EEbyNUP558 S08F25EEbsNUP499; Spider plant S08F6VEmdNUP566; pumpkin leaves S08F8VEmdNUP420; Amaranth S08F31VEmdNUP529 ; S08F24EEbsNUP495; S08F25EEbsNUP502; Cowpeas S08F31VEmdNUP531 ; S08F14EEbsNUP456 S08F25EEbsNUP497; Crotalaria	Jute plant S08F4VEmd NUP404; S08F31VEm dNUP528S08 F14EEbsNUP 455; S08F19EEby NUP474; Crotalaria S08F8VEmd NUP419; S08F28VIkb NUP571; Cow peas S08F29VIkb NUP518; S08F30VEm dNUP556

					S08F29VIkbNUP520; S08F16EEbyNUP566; S08F23EEbyNUP486; Crotalaria S08F23EEbyNUP489; Jute plant S08F24EEbsNUP496	S08F13EEbsNUP449; Local kale S08F25EEbsNUP501	
RBKF	Amaranth S08F1VIkbNUP382	None	None	None	Amaranth S08F28VIkbNUP514 Jute plant S08F28VIkbNUP570 Cowpeas S08F13EEbsNUP453; 08F21EEbyNUP483	Pumpkin leaves S08F28VIkbNUP513	Jute plant S08F1VIkbNUP383
LFF	None	None	None	None	Solanum S08F11EEbsNUP433; Cowpeas S08F18EEbyNUP473S08F18EEbyNUP473Amaranth S08F18EEbyNUP567	Solanum S08F10VEmdNUP42; Crotalaria S08F18EEbyNUP472	Cassava leaves S08F20EEbyNUP568