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Linking Farmer, Forest and Watershed

Agricultural Systems and Natural Resources Management Along the Upper Njoro River, Kenya

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1. INTRODUCTION

This research explores how recently settled farmers in the upper catchment of the River Njoro in Kenya currently perceive and utilize land, soil, and forest resources in relation to sustainable watershed management. The study was developed as part of the Sustainable Management of Watersheds Collaborative Research Support Program (SUMAWA-CRSP) to help identify agroforestry opportunities and improved farming practices that might be undertaken in the River Njoro watershed with upper catchment farmers. Based in the Njoro watershed at Egerton University, the SUMAWA Project is an international research collaboration involving the University of Wyoming, the University of California at Davis, Utah State University, Egerton and Moi Universities in Kenya, and the Government of Kenya Wildlife Service and Fisheries Department. It aims to apply a multidisciplinary approach to develop and support sustainable management of watershed resources through stakeholder participation, planning, and action in the River Njoro watershed.

The River Njoro is located about 200 km north-west of Nairobi in Nakuru District of Rift Valley Province at the eastern crest of the Mau Escarpment along East Africa's Rift Valley (Figure 1).

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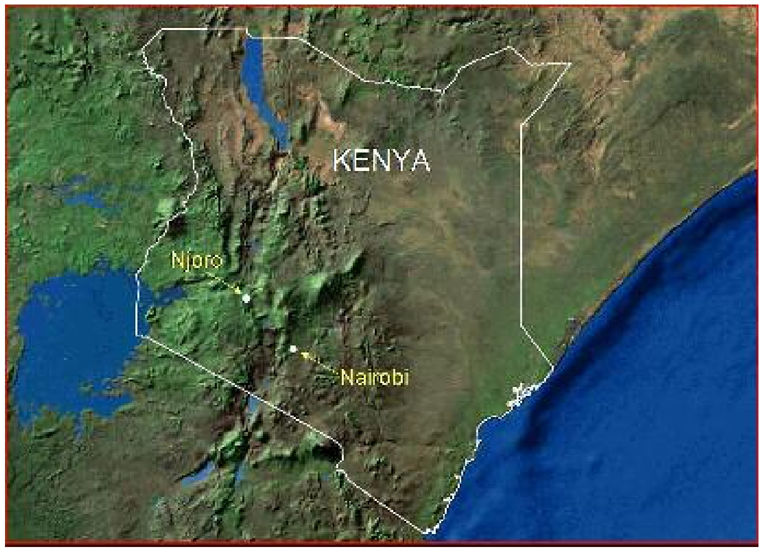

Figure 1. Location of the Study Area. (Miller 2004)

The watershed has been progressively settled and deforested in phases beginning with the lowest areas during the British colonial period in the 20th century. The most recent phase of large-scale deforestation began in the early 1990s when the Government of Kenya began allocating forested lands to the landless culminating with the decision to de-gazette significant portions of the Mau Forest (Kenya Forests Working Group 2001). In this current phase, higher elevation portions in the upper catchment have come under cultivation by immigrant farmers settling on clear-cut areas.

Deforestation continues today, although it has shifted from government sanctioned large-scale intensive actions to primarily unofficial small-scale extensive fuel and building wood extraction by local actors. Riparian vegetation is also affected, though the extent of riparian damage has not been fully documented (SUMAWA 2003). Observed changes in the river's hydrologic regime and degraded downstream water quality, combined with domestic water supply shortages have alarmed researchers and watershed stakeholders and focused attention on the relation between upland land use and water supply. These concerns have played an important motivating role in the creation of the SUMAWA Project.

The relationship between land management and water availability has constituted the basis for numerous watershed management programs worldwide (Cook et al. 2002). In tropical forests located on slopes, reductions of tree canopy cover and forest litter can result in a decrease in rainfall infiltration and subsequent groundwater recharge (Macdonald et al. 2004). Consequently, high volume surface run-off events can increase during the rainy season while infiltration and deep percolation is reduced. Despite an increase in annual runoff, the lack of ground water recharge can result in significantly reduced dry season flows (Gene 1970). In the UCRN, preliminary analysis of remotely sensed images indicates that the greatest losses of forest in the upper catchment have occurred after 1989 with widespread conversion to small-scale mixed agriculture (Baldyga et al. 2004). Uncalibrated preliminary hydrologic modeling of these changes suggests that annual stream discharge could increase substantially with the current scale of deforestation and agricultural conversion underway in the Njoro watershed (Baldyga et al. 2004).

Blending social science approaches with biophysical and economic assessments, the research focuses on farmers cultivating in close proximity of riparian zones in the UCRN and addresses the following questions:

1. What agricultural, tree, and forest use practices do UCRN farmers employ?
2. Are there significant differences in soil quality associated with various agricultural practices?
3. How does the typical UCRN cropping production system perform economically? In what way might extensive fuel wood extraction alter farm income?
4. In what way might political and historical factors influence farmers' preferences for tree and forest use?
5. Given an understanding of current attitudes regarding farm management and the historical context of recent settlement in the UCRN, what are the potential opportunities and barriers for agroforestry adoption in the UCRN?

Little research on UCRN farming systems existed before this study, in large part because the area has only recently been settled. Therefore the research has taken an exploratory and in-depth approach to examine multiple dimensions of concern related to agricultural management and watershed services. Important areas of focus have included current agronomic and resource management practices, quazi-ethnographic approaches to understand farmer knowledge and perceptions of agronomic function and environmental services, and examination of the historical and political dynamics influencing farmer perceptions and practices.

Research was organized into three distinct phases: (1) primary data collection from farmers in the UCRN, (2) secondary information gathering from organizations, agencies, and shopkeepers in the region, and (3) archival research and informant interviews regarding the political and social history of the area.

In phase one, in-depth interviews and observations were conducted during July and August of 2003 with a sample of 15 hillside farmers located within 200m of first order streams or springs, and near the remaining forest edge in the UCRN. Interview questions addressed agronomic practices and performance, economic aspects of production, soil fertility perceptions and management, the use of local tree and forest resources, and farmer perceptions of the role played by forests in water catchment and supply. Interviews were coupled with biophysical data collection and analysis for each farm, including an estimate of yields, an inventory of the frequency and uses of on-farm tree species, and soil sampling and analyses of texture, bulk density, pH, total N (N), total and available Phosphorous (P), cation exchange capacity (CEC), percent Carbon (C), and percent soil organic matter (SOM).

In phase two, price data on farm inputs and outputs and tree species characteristics were gathered from a variety of sources in 2003 and 2004. Shopkeepers and markets in Njoro town were visited for prices in July and August 2003. Where necessary, additional price data was collected from Kenyan agricultural boards, peer-reviewed journal articles, web sites, and other published documents. The agroforestry potential of UCRN tree species was evaluated based on data obtained from the International Centre for Research in Agroforestry (ICRAF).

In phase three, historical information on significant sociopolitical events in the UCRN was collected, primarily from documents consulted in Kenya's National Archives in Nairobi in August 2003, and from Kenyan newspaper articles. Supplemental information was gathered in interviews with the Rift Valley Provincial Forest Officer (PFO), Kenya Land Alliance, and Ogiek Welfare Council (OWC) staff in July and August 2003 in the city of Nakuru.

The remainder of this paper is organized into five sections. Section two provides conceptual background and historical context for the study. Relevance of this research to watershed issues in East African are highlighted and integrated farmer-based research approaches in agricultural development are reviewed. Some political and social history of the area from colonial times up to the most recent wave of deforestation and settlement in the UCRN is presented with attention paid to colonial land management and forestry practices that bear upon the current situation. Section three describes the study area and population in greater detail, and presents the materials and methods employed during research and analysis.

The research results follow, organized into three sections. Section four describes the typical farming system in the UCRN in detail based on the sample of 15 farmers. Information is provided on the agricultural calendar, inputs and outputs, and the cycle of farm management practices. This information is combined with crop yields and prices to estimate the economic performance of the annual cropping system. Farmers' soil characteristics and management practices, perceptions of soil fertility, use of tree species, on-farm tree plantings, and the environmental roles played by both on- and off-farm trees are described and evaluated in detail in sections five and six. UCRN soil management and fertilizer application practices are evaluated scientifically along with issues relating to on-farm agroforestry and forest conservation in the UCRN. These findings are compared and contrasted with farmers' perceptions and knowledge of these topics in order to identify gaps between farmer (emic) and watershed management (etic) knowledge and perspectives regarding soil and tree management. Opportunities and constraints are identified for watershed managers seeking to design agroforestry and other interventions for UCRN farmers aimed at maintaining watershed.

The paper concludes in section seven with emergent findings on the gaps and common perspectives between local farmers and scientific views regarding soil and tree resources, in the context of watershed management and agroforestry implementation. The commonalities found in this study form a starting point upon which environmental planners can develop new awareness and build trust with local stakeholders to improve land and forest resources in the UCRN. Finally, key areas of future research aimed at enhancing the performance of UCRN farming systems to reduce poverty and improve watershed health are identified from the study.

2. BACKGROUND

Agricultural systems and natural resource management are always contextual, embedded in the interplay of human and bio-physical characteristics of local environments. With this in mind, knowledge of the bio-physical environment of the Njoro watershed, and conceptual and historical context for the study and its approach, have been developed from review of relevant literature and archival material. The main influences motivating the integrated, interdisciplinary approach to the research used in this study are explained. A brief chronology of key sociopolitical events in the UCRN leading up to the current settlement pattern provides an historical perspective for understanding farmers' perceptions and management of natural resources examined later in the study.

2.1. The River Njoro watershed

The River Njoro is a second order stream about 60 km long with the Little Shuru as its primary first order tributary. Originating in the Eastern Mau Escarpment at an elevation of 2700-3000 meters above sea level (msl) and a latitude of one degree south of the equator, the river descends in a northeast direction through several ecological zones before terminating at Lake Nakuru on the floor of the Rift Valley at about 1759 msl (Chemelil 1995). The watershed covers approximately 280 km^2 (GL-CRSP 2003).

The upper catchment of the River Njoro encompasses the top third of the watershed and forms part of the Mau Forest Complex, considered one of Kenya's five major "water towers" (Kenya

Forests Working Group 2001). At approximately 900 km^2 in area, the complex is the largest remaining matrix of tree-cover in Kenya (Kenya Forests Working Group 2001) and serves as a national benchmark for the critical processes of rainwater catchment and distribution in this semi-arid country. The forest itself is now a patchy network and has been described as afromontane and "archipelago-like" (Obare and Wangwe 2004), varying between open meadows, forests and bamboo (*Arundinaria alpina*) thickets at elevated altitudes.

Comprised of tertiary age lavas, the soils in the upper Njoro watershed are classified as Mollic Andisols and are generally considered to be fertile (Ministry of Agriculture National Agricultural Laboratories 1980), especially compared to the rest of Kenya. The following information is taken from Jenkins et al. (2004), based on a summary of other research (Chemelil 1995; SAPS 2002). Long-term mean annual rainfall varies from 1200 millimeters (mm) in the UCRN to 800 mm at Lake Nakuru. Precipitation is distributed tri-modally with peaks in April (highest), August (second) and November (least). The dry season spans from January to March. Long term mean monthly air temperature varies between a high of 18.5^{o} C in March and a low of 13.5^{o} C in August. The temperature regime in the upper catchment is considered sub-optimal for the current maize-dominated agricultural production system. Spatially averaged potential evapotranspiration (ET) is estimated at 1150 mm/year across the watershed, peaking in March. Longitudinal rainfall, temperature, and ET gradients in the watershed are mainly driven by the change in elevation. Because annual potential ET exceeds rainfall in the valley floor, the upper catchment has provided important rainfall infiltration capture and supply regulation to the semi-arid valley below.

The watershed is part of the Lake Nakuru Basin and has been estimated to supply 39% of the lake's inflow from runoff (SAPS 2002). The river has historically become influent as it approaches its terminus at Lake Nakuru, disappearing into the porous fissured zones of the Rift Valley floor (SAPS 2002). Recently, more elevated portions of the river and some boreholes in the watershed have dried up, resulting in public alarm and periodic water rationing by Egerton University located in the middle of the watershed (GL-CRSP 2003).

2.2. Watershed management in developing countries

The maintenance of watershed services depends upon a complex set of interactions between biophysical and human-related forces (Cook et al. 2002). Land management in watershed uplands is of paramount concern as they serve to intercept, infiltrate and distribute water throughout the remainder of the watershed. Land management also plays an important role in shaping water quality, particularly in riparian zones. Land use and riparian management actions taken at higher elevations can have pronounced effects on downstream populations who rely on upland land management regimes for the maintenance of water quantity and quality (Blakie and Brookfield 1987).

In the global south, upland areas are generally undeveloped, difficult to access and are commonly cut off from public services. Consequently, they are usually inhabited by poorer and more marginalized segments of the rural population (Cook et al. 2002). Because the poor in these undeveloped areas are directly reliant on the natural resource base to meet their subsistence needs, when such areas experience discontinuities in environmental services, the dynamics and interactions between poverty and environmental degradation become especially important concerns. For many years, it was generally accepted that the relationship between the two could be described as a downward spiral whereby poverty forced the degradation of the environment through unchecked resource extraction that in turn reinforced poverty. While this "environmental orthodoxy" has by and large been discounted and replaced by much more subtle and complex explanatory processes (Leach and Mearns 1996), there nonetheless remains the distinct possibility that impoverished actors operating in an already degraded environment can further negatively impact the natural resource base, thus compromising environmental services. For these reasons, environmental planners often choose to initiate research geared towards improved environmental management techniques in upland areas (Cook et al. 2002).

These issues are relevant to the situation in the Njoro watershed. The UCRN is currently populated by newly settled and relatively poor small-scale farmers operating in an area recently deforested through intensive logging activities. The change in UCRN land use has been dramatic and rapid, spanning little more than a decade.

Local researchers hypothesize that these alterations, most notably the decline in forest cover, may be impacting hydrological functioning at the landscape scale, and compromising water quantity and quality services within the Njoro watershed (Shivoga et al. 2002; in press).

Because forest canopies intercept raindrops before they strike the ground, the kinetic energy intensity of drops is reduced (Stocking 1996) resulting in a more gentle impact on the soil surface than might have been if the rain path were uninterrupted, or interrupted by spotty crop cover (McDonald et al. 2003). Reduced raindrop impact assists in increased infiltration of water into the soil subsystem by reducing the potential for splashing, crusting and compaction of the soil surface. It has been noted that trees could under some circumstances actually *increase* the potential for forceful raindrop impact. Termed the "Bucket Phenomenon," this condition has been described in situations when drops collect on leaf edges and combine to develop a single, larger and heavier mass (Stocking 1996). The impact of drops falling from trees can under some circumstances result in their more forceful impact, leading to soil particle detachment and erosion. Nonetheless, this phenomenon is more an exception to the rule than the norm, especially where trees lack concave leaf structures (McDonald et al. 2003; Stocking 1996), as in the Mau Hills forests comprised largely of needle and broad-leaved species.

Without forest cover, precipitation is less likely to recharge soil subsurface storage and is more likely to result in increased runoff during and immediately after storm periods if no land management measures are taken (McDonald et al. 2002). The consequences of this process include heightened potential for downstream riparian flooding during the rainy season, and a reduction of base stream flow during the dry season, both of which are serious concerns when understood from environmental and economic production perspectives.

2.3. Study rationale

In Kenya, the importance of watershed management has gained renewed prominent following reports of perennial streams becoming seasonal and intermittent in various parts of Kenya (The Nation 2002; Shivoga et al. 2002) and eutrophication of Lake

Victoria, Africa's largest single body of fresh water (Walsh 2002; Swallow et al. 2001). Not far from the UCRN, rapid deforestation and conversion to agriculture in the Lake Elemeteita Basin in the Rift Valley prompted earlier research efforts aimed at understanding erosion and stream sedimentation processes at the watershed level (Mwaura and Moore 1991). Similar work was conducted in Baringo District of Kenya (Southerland and Bryan 1990). These past and current developments underscored the need for greater attention to watershed management in Kenya.

In response, conservationists, large-scale farmers, and policy makers have begun efforts aimed at restoring Kenya's degraded landscapes. Commercial farmers around Lake Naivasha have initiated watershed projects aimed at maintaining water quality and quality (World Lakes Network 2003). Other projects to limit forest conversion have been planned on the slopes of Mount Kenya (The Nation 2002).

The Sustainable Management of Watersheds Collaborative Research Support Program – River Njoro (SUMAWA-CRSP) represents a particularly important example of emerging watershed management efforts in East Africa. The project's overarching goal is to support local communities and stakeholders in the identification and execution of locally tailored solutions that enhance hydrological functioning and environmental services, and economic well being at the watershed scale, using the River Njoro as an experimental watershed. A unique aspect of this project is the emphasis placed on blending local knowledge and priorities with scientific research to inform the solution development process through active dialogue and exchange between scientists and stakeholders. Among the wide range of possible actions for the Njoro watershed, stakeholders and scientists have identified agroforestry as a promising approach to counter soil and forest resource degradation, and declining watershed services (GL-CRSP 2003; Jenkins et al. 2004; Shivoga et al. *In press*).

Agroforestry, the practice of integrating perennial tree crops within farmers' fields, can have positive effects on agroecosystem health, especially in the tropics (Nair 1993, 1989; Huxley 1999). Some of the stated benefits of well-designed and properly integrated agroforestry systems include improved soil fertility, enhanced agrobiodiversity, the control of erosion and the production of timber, fuel wood and other economically viable tree products (Huxley 1999). Agroforestry also holds promise on lands that have been recently cleared of vegetation and that are subject to degradation, or that have been under cultivation for only a short time (Nair 1985), as well as for the restoration of ecosystem services within a watershed context (Hai, *Personal Communication*, 2003). While the integration of multipurpose trees on farm can contribute to agroecosystem sustainability, agroforestry can also boost farm incomes, potentially resulting in a win-win situation for farmers and conservationists (Sanchez 1999).

As part of the SUMAWA project, this study focuses on understanding the behavior of farmers cultivating in the UCRN, the opportunities for agroforestry adoption, and the linkages to watershed services. It aims to contribute to the process of developing agroforestry solutions and identifying other interventions that show promise for improving land management and reducing poverty in the UCRN. At the same time, this study seeks to contribute to the larger discussion on watershed and natural resource management in East Africa. This is underscored by recognition that the River Njoro watershed is illustrative of a process of change underway both within the Mau Forest Complex and elsewhere in the region, driven by a set of larger-scale forces affecting upland catchments across Kenya and East Africa.

2.4. Methodological rationale

Balancing the twin goals of poverty alleviation and maintenance of environmental services in an endeavor such as the SUMAWA project requires that research be conducted in a participatory fashion which accounts for the needs, perceptions and desires of the local population (Kerr et al. 2002; Hinchcliffe 1999). Documenting and understanding the interplay of farmers' perceptions, practices, and knowledge base in the UCRN are at the core of the fieldwork in this study and require combining in-depth qualitative and quantitative methods with a relatively small sample of farmers. By comparing and contrasting local perceptions and practices with scientific analyses and knowledge of soil quality, yields, economic performance, tree species, and watershed-scale processes, common and divergent perspectives are revealed and avenues for cooperative action can be identified. This organizational approach to the research draws from concepts in agroecology, grounded theory, and integrated research to build a deeper understanding of the complexities underlying farmers' observed behavior and management of resources from multiple disciplinary perspectives.

2.4.1. Integrating local and scientific knowledge for agricultural development

In contrast to the 1960s and 1970s "green revolution" modus operandi, there exists no 'pre-packaged' technology that can automatically improve natural resource management in agricultural systems (Barrett et al. 2002). This is because steps to improve natural resource management depend on historical, socio-economic, and biophysical considerations, among others, that are in most cases extremely site-specific. Agroecology as a scientific discipline has arisen out of this new awareness that researchers must understand more completely the specific social, agronomic and ecological details that drive natural resource management practices in a given setting (Altieri 2004; Uphoff 2001). This "bottom up" approach to conducting agricultural development research inevitably considers local farmers' autochthonous knowledge (Richards 1985). However, some scholars prefer to discard the semantic dichotomy between 'scientific' and 'indigenous' knowledge on the epistemological grounds that it labels local knowledge as 'closed' and 'static' while viewing scientific knowledge as objective, holistic and analytical (Agrawal 1995). Agroecological approaches have sought to overturn this conflict by viewing 'indigenous' knowledge as highly relevant to local populations and as a valid source of inspiration to inform and augment scientific studies aimed at improving resource management (Figure 2).

This integrative approach allows for multiple understandings and applications of "knowledge" and thus is highly dynamic (Oudwater and Martin 2003). By matching the biophysical scientifically understood characteristics of these upland agroecosystems with farmer perception and agricultural practices, it becomes possible to develop and implement improvements in farming systems that are more likely to be sustainable (Altieri 2004; Grossman 2003; Fanzel and Sherr 2002; Hecht 1990; Gleissman

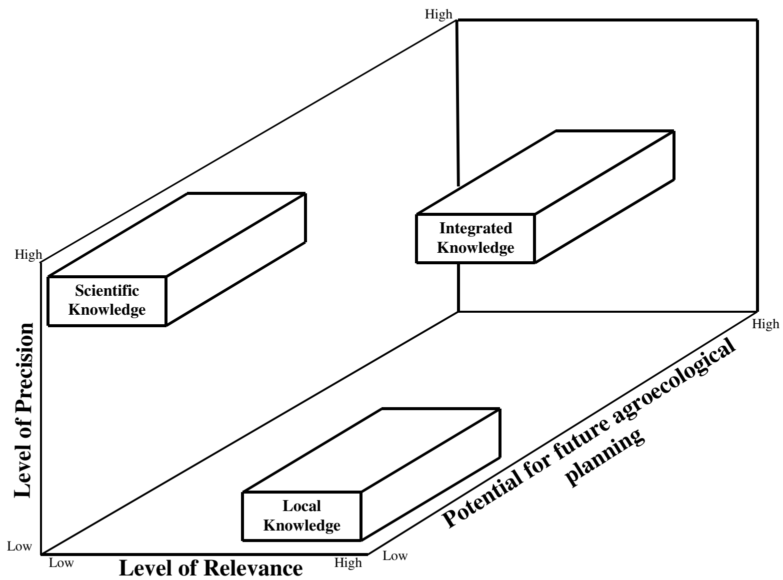

Figure 2. Conceptual diagram of the integration of scientific and local knowledge in agricultural development. Adapted from Barrios and Trego (2003).

1981). It must be understood, however, that local perceptions of environmental processes can at times be inaccurate. Without scientific input, local knowledge systems may not be able to cope with changing environmental circumstances (Barrios and Trejo 2003). This can result in ecological degradation beyond the point of recovery for existing environmental services.

2.5. Historical context for resource management in the upper catchment of the River Njoro

In any responsible study of human systems, it is important to understand the influence of historical and political forces in shaping the actions of research subjects. The study of environmental management is no exception—both biophysical restrictions and socio-political forces impact farmers' attitudes towards the performance of their cropping systems and the use of local resources. Ignorance of historical and political issues undermines the potential to develop successful conservation interventions. Daniels and Bassett (2002) posit that socio-political tensions and lack of secure land tenure in the Lake Nakuru Basin have undermined the efforts of conservation organizations attempting to implement resource management plans. Because of the likelihood of these factors also affecting the UCRN, these issues must be understood in order to better evaluate potential resource management interventions. This study draws on research literature, informant interviews, and archival material (see section three for information gathering details) to provide a partial account of the region's history coupled with an exploration of the ways in which socio-political events of the past may affect UCRN farmers' perceptions of soil and forest resource management.

2.5.1. The pre-colonial to colonial period

Before British settlement, the eastern slopes of the Mau Escarpment consisted predominantly of indigenous forests composed of *Juniperus procera* and *Olea europaea sub. sp. Africana* tree species as well as bamboo (*Arundinaria alpina*) thickets (Obare and Wangwe 2004). Even today, some of the primary woody species in the remaining indigenous forest stands and riparian zones include these natives. Although the region once supported a large diversity of vertebrate animal species, the recent increase in human habitation has resulted in their decline (Wakanene et al. 1997). Today, approximately 173 species of vertebrate animals have been identified in remnant stands of the Mau Forest Complex (Obare and Wangwe 2004). Prior to the advent of the colonial era, the area was sparsely inhabited. Pockets of the forest were inhabited by the semi-nomadic Ogiek peoples, who have lived in the area for hundreds of years (Sang 2002) subsisting by hunting, gathering and collecting honey from beehives placed high in forest tree branches (Obare and Wangwe 2004; Ogot 1978).

Interested in the extraction of forest timber resources, and to a lesser degree in the establishment of settlements in the fertile valley and lower slopes of the watershed, the arrival of the British forever changed the Eastern Mau landscape. In 1902, C.F. Elliot, the British Conservator of Forests, developed the "East Africa Forestry Regulations" which set forth comprehensive conservation and harvest guidelines that provided for the gazetting and/or degazetting of forest tracts (Loogie and Dyson 1962). These rules prohibited the extraction of fuel wood from the forest by African residents and made it a punishable offence to harvest even dead wood. From 1902 to 1908, the colonial government initiated plans to evict Ogiek peoples from forests slated for clear felling. However, this task proved to be more difficult than expected because large numbers of Ogiek peoples remained entrenched in the forests (Obare and Wangwe 2004). Where evictions were successful, clear felling of indigenous forests began throughout the mid and upper portions of the Njoro Watershed (Loogie and Dyson 1962). Increased demand for raw materials during the First World War accelerated clear felling in the Mau Forest Complex. Often these areas were eventually replanted to neatly configured rows of exotic tree species intended for timber production and harvesting, predominantly *Cypressus lusitanica*, *Casurina cunninghamiana* and *Eucalyptus globulus*. At the same time, pockets of indigenous forest were designated as natural reserves (Sang 2002; Loogie and Dyson 1962).

To facilitate the establishment of plantations on clear-felled areas that offered little hope of unaided regeneration, the British Forest Department developed pioneering agroforestry methods in the 1940s. Termed the "Tyunga" or "Shamba" systems, Africans were permitted to temporarily settle and cultivate plantation land in exchange for sapling maintenance (Obare and Wangwe 2004; Loogie and Dyson 1962). Under the Shamba system, indigenous forests were converted to exotic soft wood plantations. Kenyan peasant laborers applied to enter into contract with the colonial forest department for temporary land entitlement of up to two hectares on a yearly basis in exchange for their agreement to labor for the forest department for nine months out of the year (Loogie and Dyson 1962). Applicants who were lucky enough to be granted the hectares planted exotic tree seedlings during the months they were not laboring. Areas under seedlings were designated for annual crop cultivation. The Shamba system was for the most part considered to be a success—peasants took care of the growth of the saplings, and earned meager returns from the sale of annual crops (Loogie and Dyson 1962). The contracts were terminated after three or four years, when the saplings had grown large enough to preclude cropping. Years later, selective harvesting of timber products occurred. The British also enforced forestry policies prohibiting the felling of riparian areas by establishing large 'no-cut' zones extending in each direction from stream edges (Carroll 1947). This was done it appears out of an awareness that riparian vegetation provided useful ecological services including regulation of stream flow and hydrology.

2.5.2. Kenyan independence and the post-colonial period

Kenya's struggles for independence from the British (1952-1956) brought an abrupt end to these developments. While the majority of the fighting occurred far to the east of the UCRN, scattered incidents of violence occurred in the Lake Nakuru Basin. Full autonomy was granted to the Republic of Kenya in 1963. The difficulty involved in governing an emerging nation put forest development on the backburner, and timber extraction in the Mau Forest and the UCRN did not resume for quite some time. In 1984, the District of Nakuru still retained about 98,849 ha of intact forest, ranking it third in terms of total forest cover by district in Kenya (Kenya Forests Working Group 2001). Shortly thereafter large timber companies began clear felling in both indigenous and plantation forest tracts while Forest Department conservation and replanting programs ground to a halt throughout the region. One company, Timsales, continues to run sizeable timber operations in the mountains surrounding the watershed.

In parallel with forest extraction, the Government of Kenya began a program of land resettlement on cleared areas beginning in 1991 which has often been characterize as politically motivated. In the upper catchment of the River Njoro, the majority of Ogiek were given parcels of 5 acres (Sang 2002). A the same time, other Kalenjin communities related to the Ogiek, namely Tugen and Kipsigis, who were for the most part agropastoralists, were also settled in the area. Parcels of land were surveyed by the Ministry of Lands and Settlement and allocated to the new settlers. After tribal clashes associated with the 1992 elections in which 2,000 were killed in Rift Valley Province (BBC 1997), additional Kalenjin highlanders from the western Mau were given felled lands in the UCRN (Sang 2002). By 2001, extraction and settlement had dramatically altered the landscape of the UCRN.

Large-scale excisions of gazetted forests throughout the Mau Forest Complex and other public forests occurred in 2001 without local stakeholder consultation. However, excised lands had already been mostly felled and handed out to landless immigrants as mentioned above. The only apparent provision for collection of the publics' input regarding the 187,000 acre excision was through notices placed in the Kenya Gazette in February 2001 (Sang 2002; Kikechi 2001). Parties wishing to contest excision plans were given just 28 days to submit written notice to the Minister of Forests (Sang 2002). The excision process was difficult to stop for Kenya's sizeable illiterate and/or rural populations who have limited to no access to the Gazette. Finally, the excision process requires no environmental impact assessment.

The latter fact is particularly interesting because one of the stated justifications for the recent forest eviction of the remaining forest-dwelling Ogiek groups was that their hunting and gathering lifestyle damaged the forests. The provincial commissioner of Rift Valley Province, the Rift Valley Provincial Forest Officer, and the District Commissioner of Nakuru claimed in argument number 238 at Nairobi's High Court that the Ogiek had given up their traditional hunting and gathering lifestyle when they began keeping cattle with the advent of the Shamba system, and therefore had no claims to the forest as an ancestral homeland (Oguk and Kuloba 1999). Despite these claims, according to Obare and Wangwe (2004) the Ogiek have long had cultural rules of their own for governing forest use and management. Set forth by a council of elders called a *poisionik (*Sang 2002), these mechanisms appear to have been relatively effective in conservation of existing forested lands. These guidelines were passed down from generation to generation ensuring effective riparian and forest management and still exhibit some influence today (Obare and Wangwe 2004).

Because ethnicity has become a politicized dimension of Kenyan life due to colonial and post-colonial land and resource access policies and practices, tribalism holds considerable influence in Kenyan electoral politics (Oyugi 2002; Sang 2002; Weinreb 2001). With Moi hailing from the Tugen group of the Kalenjin ethnicity, this was of special consideration. It is now generally accepted that both the Tugen and Kipsigis peoples were encouraged to settle the Nakuru District because representatives of the Moi government were interested in increasing their voting base after the elections in this predominantly opposition party area (Daniels and Bassett 2002; Nduta 1999). The Ogiek argue that increased settlement has contributed to environmental degradation, and that the Kalenjin have destroyed thousands of beehives in remnant forest tracts. Relations between the communities are consequently strained (Sang 2002).

In 2003, President Moi finally vacated office after 25 years of semi-autocratic rule. Mwai Kibaki, who promised a revision of the Kenyan national constitution inclusive of sweeping land reform measures, was his successor. Although no formal ethnic census has been completed in this specific study area, according to study participants the demographic makeup of newly settled portions of the UCRN is estimated at 75-85% Tugen and Kipsigis, with Ogiek peoples making up the remainder.

In response to what they consider to be the colonization of their ancestral homelands, the Ogiek Welfare Council (OWC), a non-governmental advocacy organization operating out of Nakuru, has brought a legal suit against the former Moi government. Three related land claim cases have been filed by the OWC (Table 1), and although the OWC lost the first phase of legal proceedings, the decision was quickly appealed. Despite President Kabaki's appointment of new judges to hear pending land cases, the OWC suits have not yet been heard in full. Still, the OWC remains hopeful that the appeal will be successful.

The last available census of Ogiek peoples in the Mau forest complex was completed in 1988. A population of about 5,800 was recorded (Sang 2002), although many Ogiek living in the margins of the Mau Forest Complex have or are currently being evicted. Many have settled with relatives in the UCRN. Until a final verdict is reached in each of the legal cases, the government is reticent to grant formal land tenure to any resident of the UCRN. There remains the limited chance that success in any of the OWC cases could result in the partial or total repatriation of Tugen and Kipsigis settlers, though exactly how this process might occur remains unclear. As for the present, disagreement and insecurity over UCRN land holdings has resulted in tension between ethnic groups (Kenya Forests Working Group 2001). Disagreements have also arisen within the Ogiek community as to the appropriate means to regain their land and resulted in internal divisions between the Ogiek living within the UCRN (Sang 2002), further

Table 1. Legal proceedings brought by the Ogiek Welfare Council.

Case title	Legal basis	Status
Case No. 605	Claims that the Ogiek have rights to UCRN lands because of their ancestral status	Denied, appealed
Case No. 238	Opposition to Moi's settlement of Kalenjin from the W. Mau on the basis that portions of the UCRN were still gazetted when settlement was approved.	Denied, appealed
OWC Environmental Case	Focuses on improper degazettlemt of UCRN lands, the disruption of conservation efforts.	Pending

problematizing the potential for community collaboration and capacity building aimed at agricultural development.

2.5.3. Implications

These political and social dynamics pose challenges for projects like SUMAWA-CRSP that hope to encourage conservation measures and cooperative management of natural resources in the area. In a study of projects implemented in the Lake Nakuru Basin by the World Wildlife Foundation and related non-governmental organizations (NGOs), Daniels and Bassett (2002) concluded that the reluctance of the state to grant official land rights to residents has resulted in farmers' lack of enthusiasm to engage in long-term conservation measures. The presumption is that without secure claim to land holdings, UCRN residents may be unwilling to invest labor and material resources in agricultural conservation measures that require a long-term perspective to see gains. These issues are further addressed in the research conclusions where recommendations are made regarding the implementation of watershed conservation measures.

3. RESEARCH METHODS AND MATERIALS

This section describes the study site and sample farm characteristics in the upper portion of the River Njoro watershed, and presents the data collection and analysis methods used in the three phases of the study. Phase I consisted of on-farm field-based research conducted with a purposive convenience sample of 15 UCRN farmers, using a variety of qualitative and quantitative data collection methods to gain information on agricultural production practices and performance, soil management and the integration of tree resources, farmers' perceptions of natural resources and ecological processes, and collection of soil samples from farmers' fields. In phase 2, secondary information on the agroforestry characteristics of commonly used tree species in the UCRN and the prices of farm inputs and outputs identified in phase 1 work was acquired. Finally, in phase 3 background information gathered through interviews with officials from the Kenyan Ministry of Environment and Forests, local NGOs and documents retrieved from the Kenyan National Archives was assembled. Tools and processes used to collect and analyze data and information in each phase are explained in detail.

3.1. UCRN study area

The focus area of this study covers approximately 20 square kilometers (km^2) of the Upper River Njoro Watershed shown in the framed box of Figure 3. The UCRN makes up approximately the upper third of the Njoro watershed from the community of Nessuit upwards. There are several major land use systems in this portion of the watershed. These include indigenous and plantation forests, free-range herding, and smallholder agriculture. The vast majority of the small-scale farm homesteads are part of the recent wave of immigrate settlement described earlier, consisting of Ogiek, Tugen and Kipsigis ethnic groups. Rudimentary services are limited to the small community of Nessuit, with the except for one primary school located higher up in the watershed. Access throughout the area is difficult with no maintained roads beyond Nessuit. Households are scattered across the landscape. The area has no access to improved water supplies, and if sanitation exists, it consists of very basic traditional pit latrines. Njoro, the nearest commercial center to the study area, is located about 10 km away.

The farms sampled in this study are located in an area of approximately 20 km^2, stretching between latitudes 0^o 23′ and 0^o 27′ S, and longitudes 35 ^{o} 40′ and 35 ^{o} 53′ E, on both the Little Shuru tributary along the western side of the watershed and along the main stem of the River Njoro (see framed box in Figure 3). Elevations range from 2400 -2700 msl. Above the study area, the landscape is dominated by a patchy matrix of native and plantation forest tracts interrupted by clear felled areas and open pasture. Below this, the watershed stretches through more smallholder farms before being interrupted by large-scale agricultural tracts owned by Egerton University and the town of Njoro.

The 1999 census of Nessuit Location in Njoro Division (administrative units) consisted of three administrative sub-locations: Nessuit, Misepei, and Sigotik (of which one participant farmer was a community member). Of an area of 72 km^2 in size, there were 1479 households recorded and a total population of 6286 people. Estimated annual population growth in the middle and upper watershed combined (from the town of Njoro and above), from 1989-99, was 3.3% (Jenkins et al. 2004). At this time, exact population data are scarce in the study area but a socio-economic survey is underway by SUMAWA to assess area residents according to ethnic background and mode of subsistence.

3.2. Farm sample selection and description

With the assistance of a local informant, a purposive convenience sample of fifteen farmers willing to participate in the research was successively identified for inclusion in the study based on three main criteria. First, sampling focused on farmers located on slopes near riparian areas because of interest in potential soil erosion and surface water quality impacts of UCRN cropping systems. The sampling was therefore restricted to farmers cultivating on slopes within 200 meters of first order streams or springs and near remaining forest edges. Farmers were selected to represent a diversity of ethnicities and ages. Finally female-headed farm households were sought out and included in the sample. Although the selected sample is not a representative sample of the UCRN population, it was chosen to capture a broad range of diverse farm

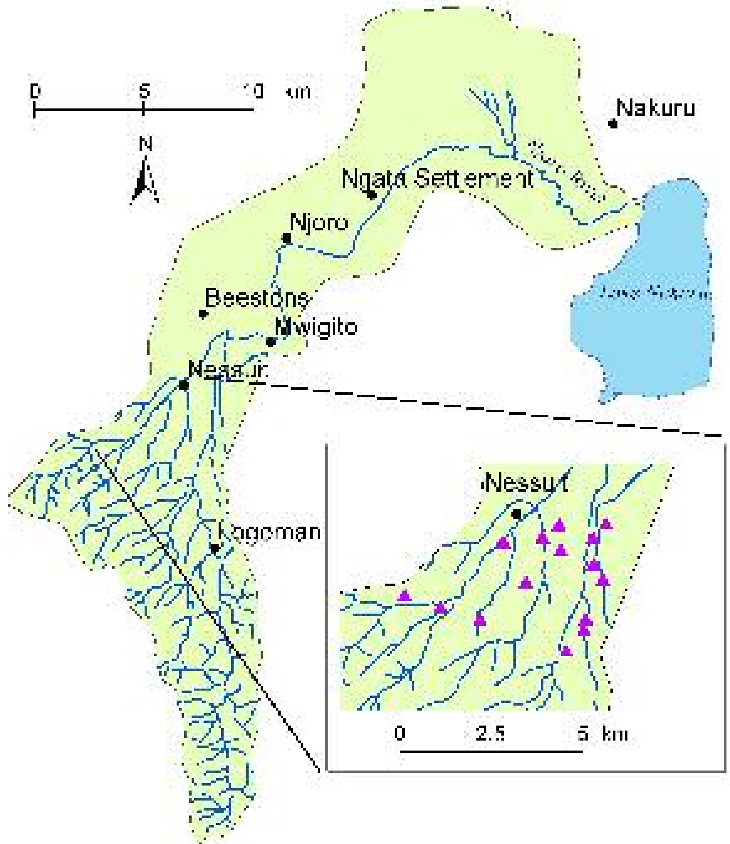

Figure 3. The River Njoro watershed and location of 15 sample farms (Thel 2004).

Table 2. Sample farm and household characteristics.

Number	Age	Family size	Land size (Ha)	Crops grown
1	28	4	2	C, PY, O§, K§, PO§
2	53	4	4	M, B, PO, PY, O§, C§, PE§
3	52	7	2	M, B, PO, PY, O§, K§
4	40	10	3	M, B, PO, PY, O§
5	22	9	2	M, B, PO, PY, PE§
6	26	9	2	M, B, PO, PY, C, K§, PE§
7	29	5	2	M, B, PO, O§
8	34	8	1	M, B, PO
9	30	7	4	M, B, PO, PY, O§, C§
10	27	3	1	M, B, PO, PY, C§, K§
11	50	7	4	M, B, PO, PY, C, K§
12	47	7	5	M, B, PO, O§, K§, PE§
13	43	1	1	M, B, PO, PY
14	55	8	1	M, B, PO, PY, PE §, O§, C§, K§
15	41	6	5	M, B, PO, PY
Mean Value	38	6	2.6	M, B, PO, PY (Most common)

§= Grown in home garden, not sold on the market.

M= Maize; **B=** Bean; **PO=** Potato; **PY=** Pyrethrum; **K=** Kale; **C=** Cabbage; **O=** Onion; **PE=** Peas.

practices and farmer perspectives that might exist in the study area. Household characteristics of the fifteen farmers in the research sample are reviewed in Table 2.

The average age of sample farmers was 38 years. Six were female, of which three were heads of household. There were no significant differences in household characteristics by farmer gender in the sample. Average farm household size was six and including extended family members (e.g., grandparents, uncles, aunts and family members related by marriage). On average, farmers had settled in the UCRN 7.5 years before the study (in 1995), with the earliest and latest arriving 29 and 3 years before, respectively (29 years is an outlier, as the next longest resident arrived 12 years ago). Eight of the respondents were Ogiek, six were Kipsigis, and two were Tugen. All but one renting farmer claimed ownership over their land. None of these held exclusive title deeds to their lands, but all displayed area survey cards provided by the Ministry of Lands and Settlement denoting rough boundaries on which they had been settled. One farming family leased a portion of their land to neighbors. Average farm size was 2.5 ha with another 0.1 ha devoted to the homestead. Intercropped maize and bean dominated, averaging 1.85 ha, with potatoes and pyrethrum each averaging to 0.31 ha.

One third of the respondents had an off-farm source of income, for example casual labor on others' farms and 9 out of the 15 engaged in fuel wood collection and sales in order to generate additional income. On average, families possessed two heads of cattle, three sheep and six chickens All of the Ogiek respondents continued the traditional practice of bee keeping, possessing on average 2 hives.

3.3. Farm-level data collection

The following sections detail the collection of field data from sample farmers. The interview methodology, participant observation, and soil sampling from farm fields are detailed.

3.3.1. In-depth interviews

A survey form and question guide were prepared for use during the interviews to gather a variety of qualitative and quantative data. Because of language difficulties interviewing farmers across several ethnicities and dialects, a local translator (conversant in English and all local languages) who was respected in the community was hired and trained to directly translate each sentence spoken by farmers in the interview process. Selected farmers were contacted and an interview appointment set up at their convenience. Interviews lasted approximately 3.5 hours and included a tour of the farm layout. Of the 15 interviews, 14 were audio recorded. Detailed notes were taken during interviews and any subsequent visits (see below). Recordings and notes were later used to compile a detailed spreadsheet of the many different socioeconomic, agronomic, demographic and tree-related practices and characteristics collected from each sample farmer. Farmers were compensated for their time by discussing soils data and suggestions for potential improvements for fertility management with them during the interview.

General topics covered in the survey included socioeconomic status, family income sources, crops planted, the agricultural

Table 3. Topic questions used to generate discussion during interviews

Soils

How are your soils prepared for cropping?
When do you till the soil?
Would you consider your soil to be fertile?
For how many years do you expect to have yields as large as the previous years? How does fertility affect this?
What are the characteristics of poor soil?
How do your soils function when it is raining?
Does the rain carry away the soil (erosion)? Where from and where to?

Forestry

What trees do you have on your farm?
What are the trees used for?
Is there a relation between the fertility of the soil and the trees?
Is the tree cover in this area declining? The same? Growing? Why?
Is there a relationship between the trees and the rain?
Is there a relationship between the trees and the river?
Why is it that some communities have chosen not to cut trees along the river?
Are you satisfied with the forests here? Why or why not?

General

What do you see as the biggest need for farmers in your area?
How do you manage crop residues?
Some people who live downriver say that they think the farming activities in this area are harmful to the river. Would you agree? Why or why not?

management calendar, crop yields, quantities consumed by the household as well as sold and purchased for each crop, pest and soil management regimes, livestock holdings, use of on-farm tree species, perceptions of soil quality and environmental services related to rainwater catchment and stream flow, and apiculture. A sample of the discussion questions used in the interviews is provided in Table 3. Despite a formal survey structure, farmers were encouraged to lead the discussion by deviating from the prepared questions to elaborate on any additional issues/themes they found to be valuable.

To assess basic inputs and outputs of UCRN agricultural production systems, agro-economic production data was collected during farmer interviews. Each farmer was asked how much time was spent to complete basic agricultural tasks such as tillage, planting, first and second rounds of weeding, harvest, and post-harvest activities. Time inputs were measured in "person-days," or the amount of an 8-hour workday required for one person to complete the task and the identity of the family member most frequently charged with performing each task was recorded. Attention was paid to understanding the division of agricultural tasks performed by different members of the household, especially those differentiated by gender. Farmers were also asked if they used external (hired) labor and the wages paid or other costs accrued for this labor. Information was also collected and recorded on the quantity, frequency and timing of other agricultural inputs, and where they came from. These included use of manures, seeds, inorganic fertilizers, animal feeds, biocides, pesticides, water, and animal traction for tillage. Household ownership and use of tools (hoes, machetes, carts, bicycles and ploughs) was similarly recorded.

Farmers were next asked to explain when each common crop (e.g., maize, beans, potatoes and pyrethrum) was planted, weeded, and harvested. Information regarding reported yields per hectare was also collected. It is important to note here that yield data reported by farmers is somewhat problematic. It is possible that farmers may have overestimated the productivity of their acres, thus skewing analysis. Nonetheless, without other yield data in the study area, information tabulated for this research is useful as an initial estimate of yields. Finally, farmers were asked about non-farm sources of household income in tandem with seasonal variations in availability and income for such work.

3.3.2. Participant observation

When farmers were not averse to spending additional time with the researcher, a participant-observation approach was used to return to the farm and take part in daily agricultural tasks in order to more fully become familiar with the farming system and its functioning. This was done with six farmers. Additional qualitative information regarding farm management and perceptions of local resources was collected and recorded during these visits.

3.3.3. Soil sampling

Twenty soil cores were collected from each sample farm at a depth of 350 mm spread evenly along transects made in a "z" shaped pattern across farmers' fields. Ten additional cores were taken along the edges of the farm. Smaller cores of intact soil were sampled from horizontal cuts in soil pits to measure bulk density. Caution was used to ensure that each core was not contaminated by any residual carbon sources (remnant roots or tree debris, etc.) Care was taken not to disturb the cores during transport, however, the difficult voyage returning from the field resulted in the fracturing of several cores (ranging from 1-8, with an average of 2). In the laboratory, the cores from each farm unit were bulked for analysis to obtain a sample representative of the broad scale soil quality of that farm's cropping unit.

3.4. Secondary data collection

After phase one field work was completed, secondary data on tree species used by sample farmers identified in phase one and price-related information for UCRN farm system inputs and outputs were gathered.

3.4.1. Agroforestry species characteristics

To scientifically evaluate the potential benefits of on-farm cultivation of tree species, additional information on the agroforestry characteristics of each species identified in the on-farm tree inventories and farmer interviews was obtained using the Agroforestree Database of the International Centre for Research in Agroforestry (ICRAF 2003). An online public information source, the ICRAF Agroforestree Database provides succinct information on the biophysical requirements and potential uses of tree species worldwide. With the SUMAWA Project's interest in agroforestry extension in the UCRN, the database was used to examine whether local tree species preferred by farmers could be more intensively promoted to achieve integrated agroforestry benefits on-farm. Queries were made and information downloaded to assess the viability of these species for fodder, fuel wood, and green manure production as well as building applications.

3.4.2. *Input and output prices*

Estimated 2003 prices in Kenyan shillings (Ksh) for all inputs and outputs identified by UCRN sample farmers were developed by visiting farmers' shops and the local market in the town of Njoro, nearest to the UCRN, and taking the average price of several locations. When prices could not be obtained locally, prices were taken from other studies of cropping systems in Kenya including those compiled by KACE (2004), the Import Administration (2002, 2001) and Nyangito and Ndirangu (1997). Published price data from other years was adjusted to 2003 values, accounting for inflation using the annual consumer price index reported by the International Monetary Fund (2004).

3.5. Sociopolitical and historical information collection

To develop background information on the sociopolitical environment within the UCRN, informational meetings were arranged with the Ogiek Welfare Council, the Kenya Land Alliance, and Provincial Forest Officer of the Ministry of Lands and Settlement of Rift Valley Province, all of whom are based in Nakuru Municipality, approximately 30 km from the study area. Discussions focused on recent settlement patterns within the UCRN and their possible consequences for natural resource management. Notes were taken during these interviews, and information gained was used to understand the political and ethnic dynamics in the UCRN. Then, documents from the British colonial administration of Kenya located at the National Archives in Nairobi were consulted to collect historic information on past forest policy and land use management in the UCRN. These sources provided historical perspective on the natural resource situation in the UCRN and enhanced interpretation of perceptions and practices recorded in the interviews.

3.6. Methods of analysis

Given the interdisciplinary approach taken in this research, a variety of analysis methods were required to analyze the range and types of field data collected from sample farms. Techniques used to compile farmer interview information, synthesize a description of farm practices and economic performance, analyze farmer perceptions and knowledge, and evaluate and analyze soil characteristics are explained.

3.6.1. Analysis of farmer perceptions and knowledge

Significant portions of the interview data collected during this study consisted of perceptions, attitudes, and knowledge expressed by farmers in response to discussion questions. Grounded theoretical analysis (emergent theory) was employed to analyze the responses contained in the recorded transcripts. Following the guidelines set forth by Glasser (1992), themes that arose from the farmers' responses to interview discussion questions were identified and organized into categories. Theme groups included the qualities of soils which perform well under cultivation contrasted with those that do not, the effects of trees on soils and crops, farmers' preferences for the management of soil fertility, the role of trees in relation to rain and water supply, and the downstream impact of land use in the UCRN.

The frequency of statements under each category or theme was recorded. Commonly expressed themes were selected as representing key areas of farmer perception or concern, and once adequately defined, a selection of quotes was chosen to represent the emergent themes. From this preliminary analysis, a literature review was conducted to provide a theoretical approach and grounding for the interpretation of the categories and underlying local perspectives that emerged in the farmer interviews.

This methodology is of considerable importance in cross-cultural studies where the imposition of the researcher's cultural values could impinge upon what is reflected in the participants' statements. Analysis of emic information that emerges from this kind of qualitative data collection and analysis is particularly useful in the development of natural resource management strategies that seek to account for and integrate the values of local populations. Local perceptions and knowledge derived from emergent analysis were later compared to scientifically derived information regarding soil, yields, and forestry resources.

3.6.2. Analysis of UCRN farm practices

Farm practices elicited during interviews and participant observation regarding soil fertility management, crop residue management, input timing and frequency, and weeding methods were tabulated. Techniques and practices used by the majority were accepted as typical UCRN farm practices. Similarly, monthly patterns in farming activities, for example tillage, fertilization, seeding, crop growth periods, weeding and harvest schedules were collected, compared, and compiled chronologically into a typical agricultural calendar using the same approach.

These data were used to construct a "snap-shot picture" of the archetypical farm production system practiced by UCRN households and presented in the results section. Thus, the majority practice among the 15 sample farmers for discrete variables such as use of fertilizer and mix of crops, and the weighted average value for continuous variables such as the level of inputs, labor, farm size, amount of land in each crop, and outputs, are captured in the description of the archetypical farm provided in section four. For example, the weighted average yield per hectare (ha) for each crop was calculated by averaging the yield of each farm, weighted by the land planted in the crop. In the case of intercropped species, per hectare yields were adjusted according to guidelines set forth by Vandermeer (1989).

3.6.3. Economic assessment of the UCRN cropping system

To assess the economic performance of the current UCRN cropping system, annual inputs and outputs were compiled for a typical UCRN farm year based on the representative operations of the archetypical farm system developed above. These were multiplied by the developed 2003 price data (see 3.4.2.) to compute the net economic output in Ksh of a single "archetypical" UCRN farm year. This analysis provides an initial estimate annual net crop income from land under current practices, and an appreciation of the underlying cost and benefit components of the cropping system, but does not provide a full assessment of farm household income.

3.6.4. Analysis of soil characteristics

Soil texture, pH, percent carbon (% C), cation exchange capacity (CEC), percent soil organic matter (SOM), total P (P), total N (%N), available P, and bulk density were analyzed in the soils laboratory at Egerton University, Njoro, Kenya. A summary of the methods used in the soils analysis is presented here, while a more detailed explanation is presented the appendix of Krupnik (005). Textural analysis of the soil samples was done using the hydrometer method (Okalebo and Gathua 1993). Acidity and alkalinity were measured with a pH meter as outlined by the Tropical Soil Biology and Fertility Program (TSBFP) (Okalebo and Gathua 1993). Percent carbon was determined by titration following the guidelines published by the TSBFP. CEC was found as outlined by the Kenyan Ministry of Agriculture (Hinga, Mucheana et al. 1980). SOM was determined by calculation as recommended by Okalebo and Gathua. N was calculated by acid digestion as described also by Okalebo and Gathua. Total P was found utilizing the ammonium molybdate-ammonium molybdiate vanadate procedure (Hinga, Mucheana et al. 1980). Available P was found using the vanadium yellow method (Okalebo and Gathua 1993). Dry bulk density of the soils was measured as the average mass of oven dry soil (72 hours at 40^{o}C) per unit of bulk volume for the soil mass in question (Hinga, Mucheana et al. 1980).

3.7. Summary

According to Barrera and Zinck (2003), research that utilizes integrated approaches to data analysis mobilizes the relationship between cultural and scientific information in order to better understand natural resource management schemes according to the local social, cultural, economic and ecological contexts which shape them. This section has detailed the process of data acquisition and analysis used in this research. On-farm qualitative and quantitative data acquisition (phase I) resulted in the identification of critical research issues that were clarified by deepened exploration during phases II and III. This progressive deepening of research and data acquisition required multiple methods of data analysis that employed both qualitative and quantitative techniques. The results produce an informative reporting of integrated information pertinent to farm and watershed management within the UCRN.

4. FARMING PRACTICES IN THE UPPER CATCHMENT OF THE RIVER NJORO

Relatively little is known about the ways in which smallholders' soil management regimes in Nakuru District where the UCRN is located, are linked to environmental services (Omamo et al. 2002). More comprehensive work has been conducted on the western side of the Mau escarpment, where many farmers have participated in agroforestry programs (ICRAF 2004). Extrapolation of the lessons learned by these projects to the Eastern Mau is problematic as soil, climactic, agronomic and social conditions vary considerably. The results from this research provide a preliminary analysis of the UCRN agricultural system in terms of biophysical performance and social issues aimed at identifying areas where development interventions might be made for improving agricultural performance and watershed health.

4.1. Cropping system description

In the study area, farm production concentrates on manual cultivation of maize with a dry bean intercrop on an average farm size of 2.5 ha. Intercropped maize and bean dominates, averaging 1.85 ha, with potatoes and pyrethrum each allocated to 0.31 ha. In most cases both maize and bean seeds are placed together in the same hole at a depth of about 150 mm when planting. Up to three maize and two bean seeds may be sown in each hole during planting. The deep placement of seeds is a result of the way planting holes are dug with a short-handled hoe. Although they did not acknowledge the potential for increased competitive stress between species that may lower yields, farmers explained that the high seeding rates were a form of insurance in case one or more seeds fail to germinate. If the household possesses cattle (on average two), they are corralled upslope and extensively grazed on communal lands. Only once a year for a week, are they permitted to graze on the farms cropped land. Sheep (an average of three) and chickens (an average of six) are also kept. Chickens are free-range and generally not fed. Animal products are mostly consumed by the household, and not sold in the marketplace.

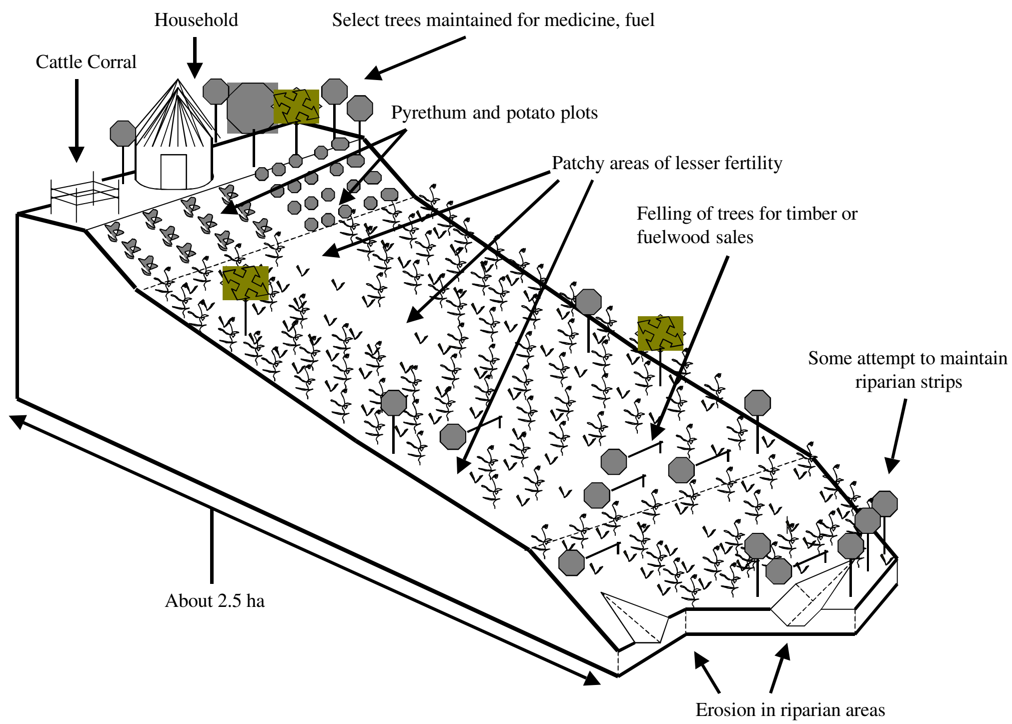

Figure 4. Layout of a typical maize/bean dominated farm in the Upper Catchment of the River Njoro.

Farmscapes are patchy, with some areas planted to maize that mature more slowly than others and others where stalks can not physically support themselves once grain set occurs. Pyrethrum (*Crysanthamum pyrethrum)* flowers are generally cultivated in separate alongside potatoes (*Solanum tuberosum* L.). Pyrethrum is a semi-perennial species which after the second season can be harvested for about three years before replanting is required. Flowers are dried, stored and sold to middlemen or directly to representatives of the Kenya Pyrethrum Board. The dry flowers are processed into a biological insecticide for sale locally and on the global market. Although larger farmers in the lower watershed may use pyrethroid biocides, due largely to its prohibitive cost, this product is not used by any sample farmers in the study area. Potatoes are replanted every four years. In interim years, smaller harvested potatoes are placed back in the soil to resprout.

4.2 The UCRN agricultural calendar

Table 4 depicts the agricultural calendar in the study area, based on the 15 sample farms. Although small quantities of other vegetables are cultivated in home gardens, maize, beans, potato and pyrethrum are the primary agricultural commodities of the farming system intended for sale. The former three are at least partially and sometimes entirely consumed by the household, with about 1/3 being sold on average.

Table 4. Planting, growth and harvesting schedule for common annual crops in the upper Njoro watershed.†

	Month											
Crop	J	F	M	A	M	J	J	A	S	O	N	D
Maize (*Zea Mays)*	**H**	**Ti**	**FP**	■	■	■	■	■	■	■	■	■
Beans(*P. vulgaris)*		**Ti**	**FP**	■	■	■	■	**H**				
Chrysanthemum pyrethrum	**H**	**H**	**H**	■	■	**P**	**H**	**H**	**H**	**H**	**H**	**H**
Potatoes(*Solanum tuberosum* L.*)* ‡			**Ti**	**P**	■	■	■	■	■	■	**H**	**H**

Key	
Ti	*Tillage*
FP	*Fertilization/Planting*
P	*Planting*
■	*Main crop growth Period*
H	*Harvest*

†=*Crops are generally planted in the spring and harvested sometime thereafter.*
•= ***There is no harvest from pyrethrum for the first*** *8-9 months of growth. After this time, the plant has reached sufficient maturity to be harvested. Harvest is possible nearly year round thereafter. Productivity begins to decline in the 3rd year of production. Consequently, pyrethrum is entirely replanted every fourth year of cropping.*
‡=*Potatoes are usually planted every few years. Aside from this, they are harvested anytime between June-November. Seed potatoes are left in the ground in intermittant years (not all are harvested) to allow regrowth.*

Slow crop growth, especially for maize on UCRN farms, could be attributed to a combination of influences including the sub-optimal climate, the choice of poor maize varieties, competition due to crowded planting conditions in each hole and an inordinate planting depth of approximately 150 mm. Seven farmers reported a significant loss of maize seedlings because rainstorms washed away their emerging crop. Quicker growth rates and the rapid establishment of root systems in particular would help to stabilize the crop against these effects. One farmer reported reduced germination rates due too excessive soil saturation or movement during heavy storm events.

Labor inputs to the cropping system occur mainly during tillage, planting, weeding and harvest periods. Weeding occurs generally twice during the maize crop growth cycle, most often in June and July as well as September-October-November, although the actual timing is the farmer's decision. All agricultural tasks are performed manually. If hired labor can be afforded at these times, it is not uncommon for farmers to employ more than one person to assist with this process. Post harvest activities are almost entirely preformed by the farm-household unit.

Additionally, timber and/or fuel wood may be harvested (although not yearly) from trees grown on the farm. The majority of farmers in the study area encourage tree seedlings that have rooted on their land, although the number surviving to maturity is generally small (less than 15). Six farmers reported transplanting naturally occurring seedlings found in riparian or forest margins onto their acres. When mature, these trees will be felled for fuel wood, pole or timber production.

4.3 Agronomic Productivity of the Cropping System

From an agronomic production standpoint, study area cropping systems show mixed performance. Table 5 reports average reported yields for the cropping system based on the farm sample.

Table 5. Sample farm annual average yields. †			
Crop	**Area (ha)**	**Yield (kg)**	**Equivalent yield (kg/ha)**
Maize	1.85	3859	2085
Beans	1.85	265	143
Pyrethrium	0.31	240	775
Potato	0.31	279	900

† = *All data sourced from field notes.*

Figure 5 compares yields for select crops in Kenya and Sub Saharan Africa as a whole with those from the study area.

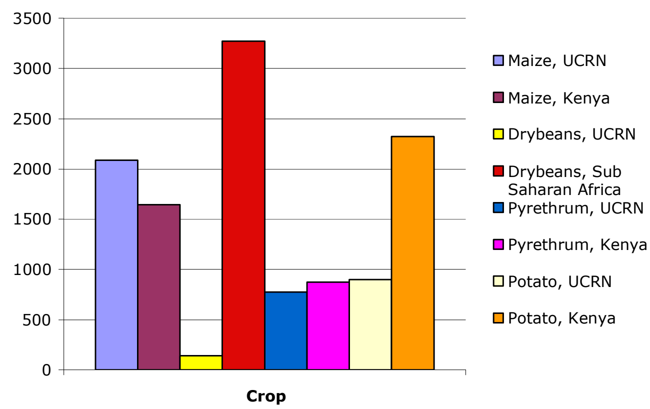

Figure 5. Yields in kilograms per hectare per year (kg / ha/ yr) in the study area compared to Kenya and Sub-Saharan Africa.

Planting densities of beans and maize as an intercrop were taken into account so as to provide a realistic comparison of yields as recommended by Vandermeer (1989). Comparative data was obtained from the Food and Agriculture Organization's on-line statistical databases (FAO 2003). Compared to Kenya as a whole (about 1647 kg /ha/year), maize yields in the UCRN (2086 kg /ha/year) are high. Nonetheless, one must bear in mind that maize production in Kenya is generally considered to be poor, and that in the UCRN, because of the cold and overcast weather it often takes up to 10 months to harvest the crop. Dry bean production statistics for Sub Saharan Africa (about 3,272 kg /ha/year) are much higher than in the study area, where production is low (about 143 kg /ha/year). This is partially attributable to increased competition for light and nutrient resources due to the dual placement of maize and bean seeds in the same planting hole. While bean is an N fixing crop, it is possible that the export of seed results in additional soil N uptake by the plant that is not returned to the system, heightening the nutrient deficit and competitive stress among the species. Additional research should be conducted to examine the effects of seed export and residue incorporation on farm soil nutrient budgets. Potato production in the study area (about 900 kg /ha/year) is similarly low when compared to Kenya (2,325 kg /ha/year). Pyrethrum production in the UCRN (about 775 kg /ha/year) is comparable to Kenya's average (875 kg /ha/yr).

4.4 Cropping system economic performance

Economic performance of the typical UCRN cropping system described above has been estimated for one year of average operating inputs and outputs. Net returns over variable costs for a year are calculated by subtracting the costs of inputs from the value of outputs. Mean prices (where multiple prices were collected), and average yields and farm practices derived from the sample data above, were employed in order to build an "average" representation of the UCRN cropping system for economic purposes.

4.4.1. Baseline agricultural structure

This section describes several facets of the UCRN cropping system pertinent to an economic analysis. Table six summarizes the main operating assumptions regarding household and farm characteristics, most of which are used in the economic analysis. Tools and bags were excluded from in the analysis because they are purchased infrequently, and can be considered fixed costs.

The typical household consists of six members, including an adult male, two adult females (usually the male's wife and a member of the extended family), and 3 children and/or unmarried youths up to approximately 16 years of age. The analysis assumes that the cropped portion of the farm is 2.5 ha, with 75% planted to a maize-bean intercrop, 12.5% planted to pyrethrium, and the remaining land designated for potatoes. Maize grain and potatoes are bagged and sold to middlemen who transport these goods downhill to markets in Njoro town or to agricultural boards in Nakuru. Dry bush beans may also be sold in Njoro. Pyrethrum flowers are harvested, dried and sold nearly year round to the Kenya Pyrethrum Board in Nakuru. The typical farm is assumed not to use any pesticides, based on sample characteristics. Each household retains two head of cattle that are grazed extensively by male youths. Milk production is low and consumed by the family alone. Manure is generally not used as fertilizer. Animals are typically

Table 6. Typical UCRN farm household variables used in the economic analysis.

Variable	Value
Area in maize/beans	1.85 ha
Area in potato	0.31 ha
Area in pyrethrum	0.31 ha
Rate of fertilizer application for maize	34 kg/ha of Diammonium phosphate
Adult males	1
Adult females	2
Children and unmarried youths	3
Hoes (farming tool)	3
Machetes (farming, fuel wood extraction)	2
Bagging sacks	40

not integrated with the cropping system as grazing and watering occur extensively. Animal products are consumed by the family in the long-run and therefore not represented as an economic return in this single year analysis. Importantly, land costs are not included in this one-year analysis for two reasons: it is a fixed cost and in the UCRN it was allotted for free by the Ministry of Forests during the UCRN settlement phase.

Family members labor on farm-related tasks for an average of 3 hours a day as the remainder of the day is designated for other necessary household and market tasks, for example, animal sheparding, water collection, cooking, etc. Hired laborers work a full eight-hour day. The number of laborers hired in varies depending on the task in question (harvests, weeding and/or tillage), farm size, household size, the number of youths present, and the amount of residual income earned from the previous years' harvests.

This analysis is based on totaling the number of laborer-hours in terms of person-days (ps-d) typically used for the tasks in question, given the assumed characteristics of the household and farm acreage. Although in reality, UCRN households rarely engage in farm activities for more than 3 hours a day, here family labor input is measured in person-days defined as an eight-hour workday. This accounting adjustment allows ease of comparison between family and hired labor (based on a full 8 hour day), as well as other labor systems based on a similar daily timescale.

The value of labor is measured using the price paid for hired labor, assuming the standard prevailing rate in 2003 of 100 Ksh2003/person-day (about 1.28 US Dollars in 2003), regardless of task and age of laborer. The exception to this assumption is for "womens' work": tasks culturally designated to be performed only by women, like maize shucking and potato bagging. The rate for these tasks in assumed at 50 Ksh2003/person-day as based on farmer testimony regarding their value. All results are calculated on a land basis, i.e. person-days of labor/ hectare, etc.

4.4.2. Cropping system inputs, outputs and associated prices

The following discussion describes inputs and their costs to the UCRN crop production system. Table 7 lists the quantity per area of land, frequency per year, and unit costs or equivalent value in 2003 for each input to the cropping system, based on the typical or average farm operation of sample farms recorded in the interviews. Where primary data were not available, best estimates based on secondary literature reviews and/or common farm practices were used to complete the model. Family labor is not paid for, but is included as an opportunity cost at the market rate for hired labor in the UCRN: 100 Ksh2003 for 8 hours of work for "male" tasks and 50 Ksh2003 for 8 hours work for "womens'" tasks. Prices and resultant economic values are reported in 2003 Kenyan shillings (Ksh2003) and converted to US dollars at a rate of 1 Ksh2003 = 0.013 US $.

Table 7. Annual average quantities and 2003 costs of inputs to the typical cropping system.

Materials	*Quantity* Unit	*Quantity* Quantity	*Cost* Unit	*Cost* Cost (Ksh)
Fertilizer				
Diammonium phosphate	Kg2.16ha[ž]	62[‡]	Ksh/kg	30[ß]
Planting Seeds				
Maize	kg/1.85ha	84[‡]	Ksh/kg	10[ß]
Beans	kg/1.85 ha	90[‡]	Ksh/kg	40[ß]
Pyrethrum	kg/.31 ha	1.4[§,‡]	Ksh/kg	240[‡]
Potato	kg/.31 ha	30[‡,•, †]	Ksh/kg	5[‡]
Labor				
Preparation (Family Labor)				
Tillage	ps-d/2.5 ha[z]	18[‡]	Ksh/ps-d	100[‡]
Planting (Family Labor, Including fertilization)				
Maize	ps-d/1.85ha	5[‡]	Ksh/ps-d	100[‡]
Bean	ps-d/1.85ha	7[‡]	Ksh/ps-d	100[‡]
Pyrethrum	ps-d/.31 ha	2[‡]	Ksh/ps-d	100[‡]
Potato	ps-d/.31 ha	3[‡]	Ksh/ps-d	100[‡]
Harvest (Family Labor)				
Maize	ps-d/1.85ha	8[‡]	Ksh/ps-d	100[‡]
Bean	ps-d/1.85 ha	7[‡]	Ksh/ps-d	100[‡]
Pyrethrum	ps-d/.31 ha	1.5[‡]	Ksh/ps-d	100[‡]
Potato	ps-d/.31 ha	2[‡]	Ksh/ps-d	100[‡]
Crop Care(Family Labor)				
Weeding	ps-d/2.5 ha	34[‡]	Ksh/ps-d	100[‡]
Post Harvest				
Shucking Maize/Sacking	ps-d/1.85 ha	5[‡]	Ksh/ps-d	50[‡]
Stacking residue	ps-d/2.5 ha	12[‡]	Ksh/ps-d	100[‡]
Pyrethrum drying	ps-d/.31ha	1[‡]	Ksh/ps-d	50[‡]
Residue burning	ps-d/2.16 ha	1[‡]	Ksh/ps-d	100[‡]
Potato sacking	ps-d/.31ha	1[‡]	Ksh/ps-d	50[‡]
Hired Labor				
Harvest assistance	ps-d/ 1.85 ha	15[‡]	Ksh/ps-d	100[‡]
Weeding	ps-d/1.85 ha	30[‡]	Ksh/ps-d	100[‡]
Tillage	ps-d/2.16ha[ž]	15[‡]	Ksh/ps-d	100[‡]
Transport				
Purchased Inputs	Trips/year	1.5[‡]	Ksh/trip	60[‡]

z - Land area tilled by the family includes all crops. For pyrethrum (a perennial) is customary for farmers to disturb the soil around the crop to allow improved water infiltration

‡- Data are based on the "archetypical" UCRN farm derived as described in preceding sections of this paper.

§- Data was multiplied by 1/5 in calculating the net value of production because seeds are purchased only every five years.

• -- Adequate field data for this crop was not collected. A "best estimate" was used regarding typical seed potato inputs to farming systems.

†- Data was multiplied by 1/4 during the calculation of the net value of production as seed tubers are bought only every four years. In interim years farmers reuse harvested tubers for seed.

ž --Includes the land area tilled in potato preparation.

Multiplying annual inputs by their associated costs gives an estimated total cost of 26,326 Ksh 2003, or 346 USD 2003 for one year of farm crop production operations, assuming the quantity of seeds shown in Table 7 are purchased every year. However, this is not the case for potato and pyrethrum, as noted earlier in section 4.1, and a more realistic average estimate of annual seed costs would be reduced

Table 8. Annual average outputs and 2003 prices from the typical cropping system. [ß]

Crop Output	Quantity		2003 Price
	Unit of Measurement	**Yield (kg)**	**Market Price (Ksh/Kg)**
Maize	kg/1.85ha	3859.1	13
Beans	kg/1.85 ha	264.55	24
Pyrethrum	kg/.31 ha	240.25 [§]	30
Potato	kg/.31 ha	900	5

ß- Data are based on the "archetypical" UCRN farm as described in preceding sections of this paper as based on farmer testimony.
§ - These data were adjusted to represent the delay in harvestable product during the first year of crop cultivation.

as explained in the notes of Table 7, resulting in reduced total costs of 22,315 Ksh 2003, or 293 USD 2003.

Under this scenario, labor constitutes the single most expensive input. Labor performed by the family makes up 44% of costs. Weeding is the most significant input task (15% of total costs), followed by tillage (8%) and maize/bean planting (3.5%). Hired labor makes up 26% of all input costs. Combined, family and hired help constitute 70% of annual costs of crop production. Fertilizer application (on average 34 kg/ha on maize/bean), constitutes 8% of total costs, and is a significant input. Despite reduced quantities estimated with this scenario, seed makes up 20% of costs.

Table 8 reviews the farming system outputs based on reported yields and their market prices in 2003. The total value of outputs is about 59,000Ksh 2003 or about 780 USD in 2003.

4.4.3. Net-value of production

For this cropping system, the annual net value of crop production is approximately 37,039 Ksh 2003, or 486.7 2003 USD. If family labor is removed from input costs, the crop production system yields 46,859 Ksh 2003 (615.7 USD) in net value or income to the household before accounting for capital investment and fixed costs. This is a positive result, suggesting that the current cropping system has the potential to create returns to investment. However, a more complete analysis would require a multi-year net present value economic analysis of the system. Such an analysis might be make refinements to the input assumptions and include a fuller accounting of additional costs and benefits (for example, home garden production, livestock, apiculture, on-farm trees, etc.). It should be noted that when compared to Kenya's average annual GNP of 340 2003 US Dollars per-person (Food and Agriculture Organization/Global Information and Early Warning System 2003), the UCRN farming system yields even more positive results. Nonetheless, this is further complicated by the fact that the annual income earned must support on average of six people. Division of the income earned by six results in a less positive result, and suggests that UCRN households subsist well below the already impoverished average income in Kenya. Therefore, it is clear that UCRN households must augment their income from non-farm sources, be they fuel wood sales, labor on other farms, or migration to urban centers where employment might be found.

4.5 Off-farm income sources

Off-farm work is difficult to acquire in the UCRN. Weeding provided perhaps the most recognized source of off-farm income, although this opportunity occurs only twice a year. Though payment is generally poor, there is a high degree of competition for weeding positions. Migration to Nakuru and even Nairobi by male family members to look for work was not uncommon, although few farmers interviewed reported that employment had been attained. Other sample households were engaged in beekeeping and limited livestock production activities in order to obtain additional income. Although returns for honey sales may be great, harvests are irregular and unreliable, and livestock products were primarily consumed by the household rather than sold. More common was non-farm income derived from fuel and wood harvesting in the margins of remnant forests and in riparian zones.

Despite the risk associated with this activity, nine out of the 15 farmers interviewed reported engaging in fuel wood collection and sale to supplement incomes. Sample farmers admitting regular engagement in these activities stated that fuel wood collection and sales to middlemen who transport the wood to Nakuru by bike represents a viable activity that can augment incomes otherwise solely reliant on farm production (Figure 6).

Figure 6. The transport of bundles of fuel wood by middlemen for sale in Nakuru town.

One farmer justified these activities by stating that "…people have the need to get the money that can come from cutting and making charcoal. If it is bad for the river we have no choice, and there is little option open for us." Another explained that "…some people have the need to get a lot of money so they will go to the river and cut the trees and then sell the trees once they have converted them to charcoal or even if they just sell it as wood in Nakuru. There is no other choice if you have the need of getting the money. This surely impacts the river, but when people have the need of money, there is nothing here stopping them."

The topic of fuel wood extraction and farmers' perceptions of environmental degradation are expanded upon in section 6.4. In terms of farming systems analysis, it is important to note that off-farm resource extraction is widely perceived as a legitimate activity that can augment farm income, regardless of the potential impact on watershed functioning. Further research should examine the dynamics of the "farm-forest" economic interface in order to identify potential policy action that could address the loss of remnant tree cover.

4.6. Summary

This section presented a description of the study area cropping system obtained from farm interviews with 15 sample farmers in the UCRN. Included was information on the agricultural calendar, agronomic productivity and a basic economic analysis of the performance of the cropping system. Results suggest a positive income balance from the cropping system, although it is unlikely that profits earned are sufficient to support the average family within the study area. Research participants suggested that fuel wood extraction and sales represented a viable income source to augment farm income. Such detail is pertinent to consideration of the impact of UCRN cropping systems upon the broader natural resource base, and for the development of integrated agroforestry practices later in this chapter.

5. SOIL MANAGEMENT PRACTICES AND PERCEPTIONS

This section presents and discusses soil qualities obtained from the soil sample analyses, soil management practices reported by farmers, and farmer perceptions and attitudes regarding soil fertility and management emerging from grounded analysis of the interviews of the sample of 15 UCRN farmers studied in this research. These findings merge scientific knowledge with farmers' perceptions of soil management issues that impact the provision of watershed environmental services.

5.1 UCRN farm soils

Soils in the UCRN are predominantly of volcanic origin. Classified as Mollic Andisols they are of adequate fertility (Ministry of Agriculture National Agricultural Laboratories 1980). Table 9 reports qualities of the soil samples taken from the sample farms. Notable is the high uniformity across all sample farms of all measured soil qualities. This is perhaps not surprising for soil that has shared a relatively long and uniform forest history and only recently been cleared of trees.

Table 9. Soil characteristics of sample farms in the Upper Catchment of the River Njoro.

Number	Texture	Bulk density	pH	Total N (%)	Total P (%)	Available P (PPM)	CEC (meg/100g)	SOM (%)
1	Sandy Silt Loam	0.94	6.20	0.85	0.11	0.002	31.92	5.53
2	Sandy Silt Loam	0.95	6.10	0.72	0.05	0.001	37.52	8.41
3	Sandy Silt Loam	0.98	6.50	1.50	0.06	0.003	26.88	6.02
4	Sandy Silt Loam	0.99	6.70	1.21	0.08	0.002	39.20	7.38
5	Sandy Silt Loam	1.01	5.80	1.03	0.07	0.002	36.12	7.22
6	Clay Loam	0.93	5.80	0.72	0.02	0.002	29.68	5.53
7	Clay Loam	0.98	5.80	1.09	0.10	0.001	37.80	7.14
8	Sandy Silt Loam	0.98	6.00	0.91	0.08	0.002	30.52	7.29
9	Sandy Silt Loam	0.87	6.40	0.79	0.06	0.001	30.52	6.74
10	Sandy Silt Loam	0.96	6.40	0.79	0.06	0.003	36.68	7.38
11	Sandy Silt Loam	0.94	6.70	1.33	0.05	0.003	32.20	8.41
12	Sandy Silt Loam	0.98	6.20	0.61	0.08	0.002	32.20	6.57
13	Clay Loam	0.97	7.00	0.91	0.08	0.002	35.56	8.10
14	Clay Loam	1.02	6.30	0.80	0.07	0.002	34.72	6.33
15	Sandy Silt Loam	0.92	6.20	0.78	0.05	0.002	36.68	6.74
Mean		0.96	6.27	0.94	0.067	0.002	33.88	6.99
Std. Error		0.000	0.000	0.000	0.000	0.000	0.000	0.000

While the sample size is small, hypotheses for further research regarding UCRN farm soils can still be drawn. Unlike Western Kenya, the upper catchment of the River Njoro soils are not highly acidic. Optimal pH for maize production ranges from 6.5-6.9 (Brittan, *Personal Communication*, 2004). The pH of UCRN sample soils ranges from 5.8-7, with three farms in the optimal range. Because of transport difficulties and other delays getting soil cores to the laboratory, only total N (%) was obtained. Although this N is generally not available for crop production when considered on an immediate time scale, the percentages shown (0.78-1.79 %) do not suggest any major long-term deficiencies. Nonetheless, it should be noted that limitations of other nutrients, for example P, could alter the long term cycling and availability of N to the agricultural system. Because UNCR soils were under forest cover for much of their geologic history, they have a rather high soil organic matter content (5.53-8.50 %), which can be taken as an indicator of potentially high fertility. Total P (0.02-0.11 %) exists in contrast to much smaller amounts of available P. Although more extensive sampling is needed for confirmation, the soil analyses point to the possibility of P limitation as a constraining factor for crop growth in the UCRN.

Phosphorous deficiency is a pervasive problem in Kenyan soils. Soule and Sheperd (2000) report that P deficiency is a major constrain to improving maize yields in East Africa's highland areas. Deckers (1993) and Sanchez et al. (1997) contend that Kenya's uplands are particularly subject to P deficiency because of moderate to high rates of P fixation in the soil. Potential P deficiency was visually indicated by the purple-red hue stains on maize leaves and stalks observed in the UCRN. These colors, which are a result of an accumulation of anthocyanins, occur when crop nutrient uptake is poor and are often an indicator of P deficiency (Haven et al. 1999). P deficiency affects crop growth by disrupting the internal transfer of energy needed to maintain plant metabolic processes. Deepened coloration of maize leaves also impacts crop productivity through lowered photosynthetic rates that can in turn reduce crop tillering and the development of comprehensive root systems. The high incidence of maize lodging (Figure 7) observed in the study area could in some part be attributed to these processes.

Figure 7. Maize lodging in the UCRN study area.

Based on these initial findings, future research should explore the potential of P limitation with more rigorous monitoring in which soil P availability is compared with crop P uptake using tissue sampling. Nziguheba et al. (2002) reported success in raising maize yields on Acrisols in western Kenya through gradual additions of 25 kg P ha^{-1}. Because of high costs associated with mineral fertilizers, it may also be useful to experiment with split applications that include local organic amendments followed by careful management of soil organic matter (Smithson and Giller 2002). Palm et al. (1997) reported that the P content in livestock manure is usually around 0.5%. Because manure is potentially available in the UCRN, it would be a candidate for split fertilizer experimentation.

Researchers may also wish to experiment with rock phosphate applications (Smithson and Giller 2002), deposits of which can be found in East Africa. Sanchez (1999) states that Minjingu phosphate rock (PR) from the north of Tanzania is “cost-efficient” and produces yields comparable to those resulting from the use of imported triple super phosphate fertilizers. However, Waigwa et al. (2003) found that sole applications of PR were generally ineffective at raising yields in acid soils in western Kenya. Instead, they also concluded that PR additions in tandem with manures have the potential to increase yields. The key to successful P fertility research will be to match any improvements in fertility with a management strategy that is adoptable to farmers, addressing their concerns regarding the high labor requirements of methods involving manure additions (see section 5.4).

5.2. Soil management practices

Table 10 describes farmers' soil fertility management techniques and perception of future fertility for maize production.

It is significant to note that inputs intended to boost cropping system fertility were generally low, with several farmers applying no fertilizers at all. While the majority of farmers in the sample used inorganic fertilizers, applications rates were very low, averaging 34kg/ha per year for land grown in maize. In only one case was animal manure used in significant quantities (number 13, 180 kg/ha), but the farmer attributed this to a single year in which he was able to access additional manure from a neighbor. However, he judged that his yields for that season were not significantly different from other years. He discontinued the practice as it was "...just too hard to work like that." Because the collection, transport and application of manure are laborious activities, most farmers described it as being economically unviable. This is the case even with manure that is heaped in cattle corrals (*boumas)* near the household.

Inorganic fertilizers applied to farm soils within the study area were in quantities so low that they were unlikely to stimulate any noticeable yield response. However, chemically-based fertilizers were perceived to contribute to yields because they are associated with modern, high yielding farming techniques widely promoted in Kenya's elementary school system. For example, a young farmer explained "All the (industrially produced) fertilizers-they are made for the crop so you will get a better response than using the local means (manures). I must use these modern methods."

All but one farmer applying inorganic fertilizers placed them in the soil either before or during seed sowing. This was the only placement of fertilizer during the extended period of maize crop growth. Under such an application pattern, there is decreased potential for fertilizer

Table 10. Farmer's fertility management practices, perception of soil fertility, and long-term fertility strategy for maize.

Number	Maize soil amendment kg /ha/year	Applications per Year	Application method	Years soil has been cultivated	Future fertility †	Long-term fertility strategy
1	62 ‡	2	Split: 1/2 with seeds, 1/2 2 mo. Pre-harvest	5	3	Additional inorganic fertilizers, perhaps manure •
2	24‡	1	Placed with seeds at planting	9	2	Incorporation of residues
3	25‡	1	Placed with seeds at planting	4	2	Additional inorganic fertilizers
4	123‡	1	Placed with seeds at planting	8	10	Rotational fallows (2 years each)
5	49 ‡	1	Placed with seeds at planting	5	5	Additional inorganic fertilizers
6	61 ‡	1	Broadcast pre-tillage	5	1	Additional inorganic fertilizers, manure incorporation •
7	98‡ and 36 ¶	1	Placed with seeds at planting	7	5	Manure
8	None	---	---	10	?	Rotational fallows
9	None	---	---	5	5	?
10	None	---	---	7	5	?
11	25‡	1	Broadcast pre-tillage	4	1	Manure •
12	25‡	1	Placed with seeds at planting	8	1	Mechanized ploughing
13	25‡ and/or 180 ¶	1	Broadcast post-tillage	4.5	2	Additional inorganic fertilizers
14	None	---	---	3	5	Additional inorganic fertilizers
15	18¶	1	Handful placed with seeds	29	5	Pasture based rotational fallow
Average	34‡ and 13¶	0.8	---	7.5	3.4	---

†= Farmer response to the question "How many years do you expect your soil to remain at this level of fertility and yields with the same management methods?"
‡ = Inorganic fertilizer: diamonium phosphate.
¶ = Cattle Manure (imported).
•= Obtained Borrowed from neighbors.
? = Respondent did not have an answer for this question.

uptake, particularly for highly soluble nitrates, as nutrients are in less demand during this early period of the crop's life cycle. Efficiency of N-based fertilizer use in the study area, like much of Africa, is likely to also be low since P deficiency can interfere with crop N uptake (Krupnik et al. 2004). Few farmers were aware of these timing or multi-nutrient issues, although it should be noted that most farmers seem to be doing the best they could given the high cost of fertilizers. Murage et al. (2000) reported that, when possible, farmers at lower elevation areas of Nakuru District will choose to sustain their farm's natural resource base by devoting economic resources to fertility maintenance. The constraining factor in fertilizer application is usually economic, and in the study area, costs are certainly prohibitive. In 2003, a kg of diamonium phosphate cost about 33 Ksh (0.40 USD). This is a significant input cost in a country where 62% of the population subsisted on less than 2 US Dollars per day throughout the 1990s (World Resources Institute 2004), and even less since 2000 (FAO/Global Information and Early Warning System 2003). As in most of Sub-Saharan Africa, farmers' low productivity and income precludes widespread use of chemical fertilizer inputs (Vanlauwe et al. 2004).

5.3. Farmer perceptions of soils

The conversion of forested areas to agricultural uses is one of the predominant causes of soil erosion in the tropics (Natural Resources Council 1993). Thus, there is concern amongst watershed managers that agricultural practices in the upper Njoro watershed could result in heightened land degradation. It is therefore instructive to examine farmers' perceptions of soil resources so that conservation planners can more effectively communicate with farmers regarding the preservation of these resources (Warkemtin 1999).

5.3.1. Sub-standard soils and erosion

As noted by Barrera and Zenck (2003) in their review of global ethnopedological studies, soil color was perceived by farmers in the study area as an indicator of fertility. This phenomenon occurred across all age, gender and ethnic categories, and is not entirely surprising given the eye-catching, bright red soil that occurs with the high degree of leaching, prevalence of iron oxides, and acidity that is associated with aged, weathered soils in East Africa. Farmers almost uniformly explained that red soils were of poor quality. One farmer, who had previously farmed on poorer soils in Western Kenya, explained that he could identify patches of infertility in his fields based on soil color: "Where the soil is red I know it is bad because it is like before I came here. In these places I apply more fertilizers." Another farmer explained: "Red soil is bad. This is where the crops do not do as well. The red soil steals the harvest from the crop."

Other signs of poor quality included soils displaying visual signs of erosion such as small rills and gullies. When asked what factors make a soil more erodeable, farmers gave answers pointing to extensive land management practices, implying that deforestation and excessive grazing were the primary influences on soil erosion. Trees were specifically identified as important in preventing erosion due to their ability to intercept and thus prevent high velocity rainfall from splashing the soil surface. A number of farmers volunteered their opinions regarding local corrective measures to reduce erosion. Responses included the planting of perennial Napier grass (*Pennisetum purpureum*) strips on slopes along contours, to the digging of silt trap terraces across the land. Despite widespread acknowledgement of these techniques only one farmer actually employed them, and these structures were in a poor state.

Although many farmers acknowledged the importance of trees in erosion control, only two stated that they were interested in using them for this purpose. One of these farmers explained that "Trees hold onto the soil because of their roots. I would plant trees along the trenches I dig if I could—I do not think it would take up too much space." When queried regarding the possible increase in competition for soil and sunlight between trees and annual crops, the farmer responded that "…if I prune them, there is no problem." Another farmer stated "I will be planting banana suckers to make trees near to the river, at the bottom of my farm. These trees will prevent the erosion." Despite these comments, employment of these methods was rare among the sample farmers. When asked why others did not use the practices, one farmer replied that other cultivators "…just do not know about them or do not care."

All farmers reported portions of their land where crop yield was poor. In each case this was attributed to the soil being more "tired, lazy or exhausted" than in other areas. Interestingly, one farmer commented that "…downhill the soil is poor, uphill the soil is worse."

This is generally true in landscapes suffering erosion processes where gravity moves nutrient rich topsoils down hill where they collect in topographic depressions or on flat areas. If this occurs, capacity of down slope areas to produce may be increased relative to up slopes where the soil 'A' horizon has been reduced. Soil data collected from this farm corroborated his perception. Upslope SOM and total N were 6.57% and 0.61%, respectively. Down slope, SOM was 8.1% and total N was 0.91%. Higher SOM and total N indicate potential for increased fertility in the down-slope area. Further studies in the UCRN should concentrate on exploring the extent and validity of the perception of differential up-down slope fertility as it could be an area of concern for farmers that can be matched with the introduction of conservation oriented management techniques.

5.3.2. Perceptions of soil fertility time horizons

Given the soil characteristics of sample farms (Table 9), farmers' predictions of future fertility contrast with agronomic assessment. Although P is limiting in the sample of UCRN soils, it is possible that current average yields could be maintained for quite some time. Nonetheless, all farmers reported relatively short time horizons when queried about the ability of their soils to maintain harvests levels. Responses ranged from 1 to 10 years, with a mean of 3.7. This could be due to farmers' already significant dissatisfaction with yields and the extended delay between planting and harvest. There also remains the possibility that these newly arrived farmers have simply not adjusted their perceptions to the soils in the study area, or that recent past experiences of farming on poorer soils elsewhere have influenced their short predictions. One explained that "The soil may first be very good here but look, my crop is now bad and it is going to be completely bad in about three years. Then I will have to do something else."

When asked about their plans for correcting fertility decline, two farmers admitted they had not considered a strategy. Best management techniques arising from traditional agriculture tend to be place specific, having developed over time in response to unique cultural and ecological influences (Altieri 2004). Thus, it may simply be too early for immigrant farmers to have developed a detailed knowledge of agroecological conditions in the study area. Four farmers reported that they would apply additional inorganic fertilizers, although they could not explain how they might afford the costs. Others explained that they would attempt to combine applications of synthetic fertilizer and manure, but not necessarily in mixed forms. If additional land and income were available, they responded that they would fallow portions of their cropland in order to restore fertility.

The use of pasture and fallow techniques appears to be a rarely preferred technique for the upkeep of soil fertility among the sample farmers, with the sole exception of one farm household whose deceased relative championed the technique. The lack of interest in pastoral fallows can be attributed to the expensive opportunity cost associated with taking land out of production. One farmer explained that "Using the fallow is very expensive—I mean it does not cost anything to do it, but there is no crop then. So one has to be able to have money for this time, and this is very difficult. So I can not say, perhaps I will do it but I can not be sure now." Finally, one farmer said that they would attempt to incorporate crop residues into the soil. "If I can, I will put back the maize stalk after the harvest into the soil. It is more work, but maybe over some years it will make the soil better for those crops."

From a long-term fertility standpoint, management techniques inclusive of the application of organic amendments (manure, crop residue), be they through fallows or direct application to soils, are desirable as these materials increase soil organic matter content and thus improve soil structure and water retention while simultaneously reducing runoff rates. These approaches are encouraging when considered from a watershed conservation standpoint, although it may take years of fallow before a significant level of fertility is restored in the agronomic sense.

5.3.3. Good soils and their relation to trees

Farmers often linked soil organic matter content to soil quality, which was sometimes correlated with tree cover and the dropping of leaves on the soil. "If the farmer is good on his farm, and he weeds carefully and feeds back the weeds to the soil, the weeds will rot and then the soil becomes good. Trees shedding of their leaves also help the soil a little in the same way." Farmers commented on the qualities of good soils in tandem with those that are poor. Soil color was often taken as a primary indicator of quality and fertility: "Black soils have more energy than red ones. Because of this, the black soil becomes fertile in itself."

Others noted adverse effects of tree-plant competition and its impact on crop yields. "The farmer who prunes his trees should have no problem with the crops near the trees. But lazy farmers will lose their crops, and sometimes it is difficult to have time to cut back the trees." Another commented, "…some trees may take from the soil if planted close to the maize." This was echoed by a farmer who explained "…when planted closely to the maize, the trees will make it so the maize can not grow." It is important to note that only one farmer had thought of using tree leaf litter as a green manure for soil fertility enhancement. He was aware of this technique from previous employment on a large farm in Western Kenya where cut and carry fodder/green manure methods were practiced. Nonetheless, he was averse to using the method because the labor involved was viewed as a constraint.

5.4 Summary

Soil quality indicators and soil resource management practices by farmers in the study area have been presented. Phosphorous deficiency was identified as a potential limiting factor for maize productivity in the region which needed further research and investigation. Information was presented regarding farmers' use of soil amendments, their perceptions of poor soils, and soil fertility time horizons (the time for yields to decline significantly due to exhaustion of soil fertility). Finally, farmers' views of the interconnectedness between soil fertility and trees were discussed. These subjects are particularly important in the development of integrated agroforestry practices geared towards the maintainance and improvement of soil fertility.

6. ON- AND OFF-FARM TREE RESOURCES MANAGEMENT

What follows is a discussion of farmer's use, perceptions, and management of tree and forest resources in relation to common trees found on- and off-farm in the UCRN and to watershed hydrologic functions. Interview discussions centered on the value of tree resources in the riparian zone and in state owned forest/plantation reserves located 1 to 3 kms uphill from the study area. An analysis of tree use and management practices, and forest product extraction reported in the interviews is presented. In each case, the potential for developing an agroforestry intervention is assessed.

6.1. Tree resources inventory

Farmers identified numerous tree species that occur both on their acres and in neighboring riparian zones and forests. The complexity and depth of knowledge and understanding of trees is shown in Table 11.

Table 11. Common trees found on and near-farm in the study area and their associated uses.

Scientific name	Frequency †	Uses§	Additional comments
Hagenia abyssinica	R	F, M	Fuel wood.
Morus alba	R	T, F, FR	Propagated vegetatively.
Zanthoxylem gilletti	R	T, F, M	Timber and fuel.
Cussonia spicat	C	M	A common riparian species.
Euclea divinorum	C	T, F, TH, M	Used in traditional medicine.
Croton macrostachyus	C	TH, M	Preferred as a building material, can be used for fodder.
Ficus thonningii	C	R, O, M	Though not utilized in the study area, the leaves can be used as green manure.
Grevillea robusta	C	T, F, CH	Although not practiced in the study area, the leaves can be as fodder.
Schinus molle	C	F, BF, M	Can be used in cooking and traditional medicine making.
Teclea simplicifolia	C	T, CH, M	A riparian species.
Warburgia ugandensis (W. salutaris)	C	F, M	Medicinal applications.
Dombeya goetzenni	C	BF, F, T	Also bow/arrow construction.
Eucalyptus globulus	C	T, F	Problematic for soils and water conservation.
Podocarpus falcatus	C	T, F, TH	Beehives are often placed in the trees branches.
Cupressus lusitanica	EC	T, F	A former plantation species.
Juniperus procera	EC	T, BH, F	Sometimes planted to denote property lines.
Olea europaea subsp. africana	EC	T, F, BF, M	A prized on-farm species.
Pinus patula	EC	LI, T, TH, F	Logged industrially for paper pulp.
Polyscias fulva	EC	BH	Though not utilized in the study area, the leaves can be used as green manure.
Prunus africana	EC	T, F, M	Exported in parts of E. Africa as a medical ingredient.

†= Respondents' impressions of tree frequency in the upper watershed: **R** = Rare; **C**= Common; **EC** = Extremely common
§=Respondents reported tree uses: **F** = Fuel wood, **M** = Medicinal Uses; **T** = Timber; **TH** = Tool handles; **RO** = Rope fabrication, **B** = Bee fodder; **BH** = Beehive Fabrication; **LI** = Timber (industrial); **FR** = Edible fruits; **CH** = Charcoal production.

The majority of farmers explained that the primary attraction of local forest resources was to supply timber for building and fuel wood. Four men noted the medicinal potential of trees, although they did not explain their specific uses. Women, however, were generally capable of describing in detail the medicinal uses of local species. Only Ogiek respondents commented on the need to conserve tree resources because they were "beautiful" and a source of fodder for bees. This is not surprising as Ogiek are known for apiculture and their conservation ethics (Obare and Wangwe 2004; Ogot 1978). Importantly, three species in Table 11 (*Polyscias fulva*, *Ficus thonningii* and *Grevillea robusta*) can be used as a green manure or fodder (ICRAF 2003), although only one farmer was aware of this potential use. Each of these species was classified as common or extremely common in the study area, and thus holds potential for further domestication and use in agroforestry systems for the UCRN.

6.2 Farmer preferences for on-farm tree planting

Trees are also important when considered in a social context. Of the 15 farmers interviewed, 13 responded that if they were to plant additional trees on their farm, they would choose to place them around the perimeter of their land. In light of the land tenure concerns in the study area, this may not be entirely surprising. Historically, under customary law in parts of East Africa, the planting of trees along boundary lines has been used to demark the limits of a farmer's property (Fortman 1987). During the colonial administration, this practice was given a sense of legitimacy as forest officers on occasion recognized lines of trees as boundary markers (Troup 1922). Postcolonial land reform in Kenya reduced the legitimacy of these practices for proving small holders' right of access to land (Dewees 1995). Today, customary law has less influence upon the state's legal definitions of land tenure and property, although in many rural areas of Kenya land cases may still be herd by local elder 'courts' and recognized by local authorities (Sang 2002). In the study area, however, these traditional methods are less likely to be practiced while the legality of land holdings has yet to be completely decided by the Nairobi High Court. However, the historical influences of cultural legitimacy associated with boundary plantings may be reflected in farmers' near universal desire to establish trees along the perimeter of their farms.

Fortmann (1988) explains that for East African persons, and in particular for those lacking formal land title deeds, planting trees is often perceived as establishment of the right to access, produce, and to collect materials from the trees, even if control of the land upon which plantings are located is relinquished. Thus, farmers in the study area may well be interested in the use of trees to enforce customary law in an effort to strengthen clear claim to lands over which their statutory ownership is still in debate. "If I plant the trees along the farm, then it will be known that this place is mine, and that I will farm here in the future," concluded one farmer.

The claim put forth by Daniels and Bassett (2002) that land insecurity could hamper conservation and reforestation efforts in the River Njoro Watershed may in the case of the UCRN turn out to be not entirely correct. Instead, when farmers actively seek to legitimize their status as holders of land resources, conservation interventions based on tree planting may hold particular promise. Nonetheless, environmental planners must consider the social ramifications of promoting tree establishment in an area experiencing ethnic tensions over land, especially where the legality of land holdings is still in question. These revelations underscore the need for planners to fully understand the social meanings of trees in relation to customary law and land tenure issues in the UCRN before extension activities begin.

6.3. Trees and their relation to climate and hydrological patterns

Farmers strongly correlated trees with the maintenance of climatic patterns. Remnant stands of primary forests were attributed with "collection" of moisture from the air. "The trees attract rain to these lands because they stop the wind from flowing. See, like over there." Pointing to a large bank of rain clouds positioned over the western edge of the Mau Escarpment, the farmer continued, "…the forest will now make the rain fall from the sky because the forest has stopped the cloud from moving." Riparian trees were associated with the continued functioning of stream flow because they shade river waters from the intensity of the summer sun. "This means that in the dry season, when it is hot, the trees will keep the river from going up and away into the air. They keep the river from drying." This interviewee had resided in the region for their entire life. "I remember that even the British set large reserves along the River Njoro and the side streams. In these places you could not go to cut trees or to cultivate because it would make the water to be lost." Referring to the Little Shuru Tributary, they continued: "You know, in the last few years all of the rivers in the area have dried but this one and this is because there are many trees left here. We had a lot of shade on each side of the river for a long distance."

Although farmers' perceptions of riparian and forest tree cover do not match scientific explanations of the role and function of tree vegetation in hydrologic processes at the watershed scale, there is a general understanding among sample farmers that trees provide important environmental services in the maintenance of rainfall patterns and water supply. Because there is an understanding of the importance of these upland features, SUMAWA's extension efforts could focus on participatory education that builds on this prior local knowledge regarding the roles played by tree cover in rainfall capture and stream flows.

6.4. Forest product extraction and perceptions of environmental degradation

As noted above, some farmers interviewed admitted engaging in forest product extraction to augment meager farm income. According to respondents, cutting sometimes occurred at night to avoid detection. Others felled trees in riparian tracts nearer to their place of residence. Despite involvement by UCRN residents in these activities, several respondents expressed concern for the impact that tree felling and charcoal making might have on water quality and quantity.

"These people destroy the river because they cut right up to it and burn it there for charcoal. Then they cultivate this land, right there, and it is a very bad problem," explained one farmer. Such issues were echoed by another farmer who explained that "…the water has been destroyed. When the trees are cut there by the river for making charcoal, or even for poles, this can be very bad. We have trees by the river, it can prevent the soil from being washed into the river and away from the shambas. But look now, every day there are fewer trees by the river."

All interviewees denounced riparian zone clearing activities both on and off their farms as detrimental to soil and river quality. Nonetheless, on many respondents' farms, riparian damage and clearing was visible. Only a minority had greater than a 1 m buffer of vegetation between cropped lands and the river. There is also a possibility that little attention was paid to riparian buffer strips by survey teams from the Ministry of Forests when UCRN lands were settlement after clear felling had occurred (Provincial Forest Officer, *Personal Communication,* 2003). A farmer who had resided in the UCRN for five years explained that "…most of the people living here, near the river, they do not keep the trees along it. They will tell you that they do, because they feel guilty. But there is too much of a need for that land and for the money from the wood, and because the crops are not good, there is the need of more space to cultivate. So now you see, this land is becoming for the crops, not for the trees."

Interestingly, several farmers commented that they were not to blame for the environmental problems in the watershed. While they still agreed that the clearing of remnant riparian trees was harmful to watershed hydrology, they explained that *Timsales*, the logging company that formerly operated in the area, was in fact responsible for impaired watershed health. One man commented "…it is the government and the timber companies that have been doing all the cutting. I am just a farmer. All I can do is take what remains, but it is these people who took away from here truckloads of trees." He concluded by stating emphatically that "…since they have been taking the trees here, the rainfall has declined and the air has gone dry. Because of this, we have no better option than to take what trees may be left, because the crops may be bad. But it is not the farmer who did most of the taking (of trees)."

Such comments are important in that they implore future research in the UCRN from a more strictly political-ecological approach that examines the question: Do the diffuse actions of many small landholders engaged in forest extraction and riparian zone clearing outweigh concentrated industrial logging activities further away from riparian boundaries? Only continued analysis can unravel the extent to which each land use system impacts the watershed. Nonetheless, one point remains clear: the continued unchecked settlement of clear felled lands on slopes and close to riparian tracts entails heightens the potential for detrimental environmental effects.

6.5 Summary

This section reviewed issues relating to UCRN farmer tree planting preferences and perceptions of tree resources in the study area. An on-farm tree crop inventory, farmer motivation for tree plantings, perceptions of trees and their relation to climactic and hydrological patterns, and forest product extraction attitudes were presented discussed. Knowledge of these issues is can be particularly valuable in designing and promoting integrated agroforestry systems for improving natural resources conservation in the UCRN.

7. CONCLUSIONS AND IMPLICATIONS FOR WATERSHED MANAGERS

For SUMAWA researchers and watershed managers to collaborate with farmers in the UCRN, it is instructive to conclude this exploratory research by noting the "gaps" and "commonalities" between farmer and scientific perspectives regarding management of soil and tree resources in the area. A variety of qualitative and quantitative methods, examining the socio-cultural, historical, agronomic, and bio-physical dimensions of UCRN farming practices, knowledge and perceptions of a sample of 15 farm household located near the River Njoro's edge in the study area, has been used to identify these gaps and commonalities, an economic analysis of annual crop production was performed, providing an initial estimate of the economic viability of the current UCRN maize-dominated farming system. The cultural and political context of recent settlement in the UCRN, and its implications for developing farm-based interventions, was elucidated through historical research. In combination, the research findings point to areas for further investigation and provide guidance for developing agroforestry promotion within the UCRN as part of the SUMAWA project.

7.1. Gaps between local agroecological knowledge and scientific points of interest

The following gaps between local agroecological knowledge and scientific points of interest for agricultural development and improved natural resource management in the upper catchment of the River Njoro were identified:

1. Despite farmers' universal expectation that maize yields would decline within the next few years, agronomic assessment

suggests a longer-term ability for UCRN soils to support maize culture at current, albeit low-yielding levels.

2. While farm soils analysis points to possible deficiencies in available P levels, farmers were unaware of any specific nutrient deficiencies that might have adverse effects on crop productivity.
3. Farmers were similarly unaware of the need for optimal synchronization between fertilizer application and crop uptake in maize, resulting in misapplication and inefficient use of fertilizers in the current maize production system.
4. Despite scientific concerns regarding the sub-optimal climate for maize production, farmers appeared unaware of these issues.

Gaps between local knowledge and scientific concerns were also identified in areas related to agroforestry and forest resources. The gaps in agroforestry-related perspectives both problematize and present opportunities for further tree planting efforts within the UCRN:

1. All study participants had interspersed planting of trees among agronomic crops and a generally robust knowledge of the utilitarian benefits of local tree species. Nonetheless, they were not managing on-farm trees in an integrative way to achieve the benefits of agroforestry, nor were some specifically important tree applications understood. For example, despite the potential use of three common tree species for fodder and/or green manure production, these applications were largely unknown. Only one farmer was aware of green manuring for fertility maintainance, although he did not associate this technique with any local tree species despite the availability of three in the area.
2. Farmers reported a preference for farm perimeter planting of trees. Rather than making use of trees for agronomic benefit, establishment was regarded as desirable in order to develop stronger ties to land in this tenure-insecure area.

7.2. Common perspectives between local farmers and scientists

The research has also revealed the following common perspectives between local farmers and scientists regarding soil and tree resources. These form a starting point upon which watershed managers can develop new awareness and build trust with local participants:

1. Despite gaps in knowledge regarding soils and fertilizer applications, farmers expressed that soils of optimal production quality were darker in color and had higher organic matter content. They also commented that better quality soils were in part the result of long-term tree leaf decomposition. This mirrors scientific knowledge regarding soil quality and the use of elevated soil organic matter content as a proxy for fertility. This shared belief presents a foundation on which watershed managers and agricultural agents can build educational messages and extension activities for farmers regarding the use of green manure techniques.
2. Although farmers, widely speaking, did not actively manage on-farm tree resources, most were nonetheless aware of the need to intensively manage trees to minimize competition with adjacent agronomic crops. Farmers often cited the large labor investment as the reason for not making use of such strategies.
3. Many farmers perceived the benefits of maintaining forest resources, both within the riparian zone and across the upper catchment, to preserve stream flows in the river although their explanations of causal processes differed somewhat from those held by scientists.

7.3. Areas for further research

This research was exploratory, occurring in a recently settled area with poor immigrant farmers. An important purpose was the identification of key areas of future research aimed at improving the UCRN farming system to reduce poverty in addition to improving watershed health and natural resource management. The following areas for further research have been identified:

1. Full investigation of the apparent P deficiency in farm soils is needed to determine if crops are still able to assimilate the nutrient. Analysis could be done by comparing P-deficiency evidence from soil analysis with P-deficiency status of plant tissue. Should P deficiency in plants be confirmed, research into cost-effective and adoptable interventions for partial or full correction of any P-deficiency problem should be conducted. Analysis to determine if the soil is P-fixing is recommended as part of the design of experimental farm trials of applications of

P-fertilizer, rock phosphate, manures, crop residues or combinations of each to determine impacts on yield, feasibility, and cost-effectiveness from the farmers' perspective.

2. For those farmers already using chemical fertilizers in the UCRN, proper fertilizer application regimes for maize, addressing both the timing of applications and the supplementary use of manure to maintain soil organic matter levels, need to be developed for the UCRN agricultural production setting. Given the participatory approach of the SUMAWA project, this should be done by conducting farmer-led participatory trials. Each experiment should include an economic analysis to judge the practical viability and adoptability of the regime.
3. Research should be conducted on on-farm tree integration methods that are cost-effective and that minimize labor inputs as this is an important constraint for tree management. Three common UCRN tree species (*Ficus thonningii, Grevillea robusta, Polyscuas fulva)* identified by farmers hold potential for agroforestry applications (fodder and/or green manure) but are not currently understood or perceived by farmers as having these characteristics. Joint investigations with farmers should critically evaluate the agroforestry benefits of these three species jointly in the context of farming practices and operations, in particular, fodder and green manure production, and the degree to which they would reduce extensive fodder consumption activities, improve animal health, and maintain soil fertility. Because these three identified tree species with green manuring potential do not concentrate high levels of P in their leaves, it will be particularly important to consider split applications of manure with an available P source (perhaps rock phosphate), if P deficiencies in plant growth are confirmed.

7.4. Research implications for watershed managers

A goal of this research was to identify opportunities and constraints at farm level for agroforestry promotion by SUMAWA in the UCRN as a potential intervention to improve farming productivity together with management of natural resources in the River Njoro watershed. The following issues emerge from this research:

1. Interventions at farm scale must take into account the labor intensiveness of agroforestry management and the reality that farmers may not consider these techniques to be cost-effective given other competing opportunities for returns to labor, particularly those related to forest product extraction.
2. The research has shown that farmers in the UCRN have a strong desire to plant trees on their farm, however, currently this desire appears motivated largely by a need to establish perimeter boundaries to increase tenure security of land holdings, and not by agroforestry benefits. The implications of this motivation and of increased boundary tree planting should be further explored with small groups farmers and scientifically considered when pursuing the development of any tree planting interventions in the UCRN.
3. Labor constraints and preference for boundary planting could reduce the potential for on-farm plantings to be used in ways that augment soil fertility and/or fodder production. Farmers' current unawareness of green manuring strategies and species are clearly also important barriers to adoption that would need to be overcome, although common understanding of the role played by leaf decomposition in soil building provides a departure point for explaining green manure techniques. The strong interest in tree planting represents an opportunity for further on-farm tree establishment. It is possible that boundary plantings could be implemented as an integrated natural resource management technique, especially if multi-purpose species are chosen that double as fodder and fuel wood banks, or as a source of poles and timber for construction.
4. Moving from on-farm to extensive forestry, the apparent profitability of forest fuel wood extraction could be a barrier to adoption of the integrated agroforestry management techniques outline above. Public education on the value and importance of maintaining extensive forest complexes along with farmer education on agroforestry benefits could assist in changing attitudes towards deforestation. Economic research into the dynamics driving illegal tree felling in areas like the Njoro watershed is needed to identify appropriate scales of policy action in Kenya. Improved enforcement of deforestation restrictions may also be needed, although care should be taken

to present a diversity of adoptable income generation strategies to impoverished farm households before restricting this activity.

5. Historical developments behind inter-ethnic dynamics within the UCRN provide additional insight into why farmers engage in extensive resource extraction activities. Lack of land tenure and heightened recent migration by ethnic groups from western Kenya to the UCRN, combined with low agricultural yields, have contributed to farmers' perceptions that their own lands are resource limited. Consequently, extensive resource extraction is motivated in part by farmers' lack of intensive management options. Lack of resolution of the land tenure issues in the UCRN complicate the prescription of more sustainable land use practices. Until land tenure is granted by Kenyan government authorities, it may be necessary and important to selectively promote conservation efforts and agronomic interventions that are most likely to provide direct and immediate benefits to farmers rather than ones that require long lead times to achieve on-farm benefits. Promotion efforts should also be carefully designed to avoid being seen to threaten farmers' claim to production and land rights within the watershed. This should be possible through direct and personalized engagement that allows farmers as a community in the UCRN to take charge of and participate in planning agronomic research trails and local intervention actions.

7.5. Conclusion

By framing this research in a context of watershed health and environmental services, this paper has described some of the ways in which UCRN farmers regard soils and tree use, in the context of complex agroecological processes, at a variety of scales ranging from their own acres to riparian zones and forests tracks. Consideration of bio-physical characteristics of these upland agroecosystems in tandem with farmer behavior, perceptions, economic analysis, and improved resource management methods provides deeper insights for environmental managers concerned with the implementation of improved farm and land use systems in the highlands of East Africa. To this end, this research points to practical directions for closing the scientist-farmer gap and converging on mutually meaningful methods of sustaining livelihoods while improving natural resource management.

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